A Desk Reference for NEPA Air Quality Analyses

Prepared for

USDA Forest Service

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Executive Summary

This NEPA Air Quality Analysis Desk Reference is designed to assist Forest Service air quality staff in preparing air quality analyses for environmental assessments (EAs) and environmental impact statements (EISs). The user is assumed to have some fundamental knowledge of air quality concepts, rules, and regulations, as well as a working knowledge of the NEPA process. The primary emphasis of the document is on presenting the methods for estimating air pollutant emissions from some common Forest Service projects and activities.

The desk reference is divided into six chapters:

- **Chapter 1:** Introduction to the desk reference, including the purpose and scope of the document and the intended audience.

- **Chapter 2:** Overview of the NEPA process, including a description of the key elements of a NEPA air quality analysis. Chapter 2 also provides guidance on how to obtain detailed information on the air quality regulations in each state.

- **Chapter 3:** Comprehensive list of emissions sources for Forest Service projects and activities, and detailed descriptions of calculation methods available for estimating emissions from Forest Service projects and activities, including equations and examples where appropriate. Chapter 3 includes a summary of mitigation measures available for reducing emissions from these projects and activities. The emphasis of this chapter is on the emissions of "criteria" pollutants (such as sulfur dioxide, nitrogen oxides, and particulate matter), but the chapter also includes a discussion of the potential for emissions of the 189 hazardous air pollutants identified in the 1990 Clean Air Act Amendments.

- **Chapter 4:** Synopsis of available modeling options, organized by project or activity.

- **Chapter 5:** Synopsis of ambient monitoring techniques available to assess background conditions and changes to those conditions from proposed projects, also organized by project or activity.

- **Chapter 6:** References.

In addition, the appendices include a glossary and description of common air quality abbreviations and acronyms.

One of the most difficult tasks facing NEPA analysis preparers is deciding when to consider air quality issues and concerns in the EA or EIS; that is, deciding when impacts are likely to be "significant" (not to be confused with *significant effect*). "Significance", as used in NEPA, requires consideration of both context and intensity. Context refers to the temporal and spatial scales of the impacts (for example, short term or long term; site-specific, local, regional, or global). Intensity refers to the severity of the impacts at these varying scales (40 CFR 1508.27).

Following are some general guidelines for considering when air quality issues and concerns are likely to be considered "significant" in the NEPA process:

- If the project is highly controversial and therefore likely to receive intense public scrutiny.
- If the proposed source is located near a Class I area.
- If public health or safety could be affected by emissions of any regulated pollutant. This essentially includes any project or activity that emits pollutants, including dust.
- If the proposed project has both positive and negative impacts. For example, prescribed burning might produce significant increases in smoke emissions in the short term, but significant decreases in smoke emissions over the long term through reductions in fuel loading and reduced hazard of large, high-intensity wildfires.
- If the project or activity produces emissions of pollutants whose health or ecological effects are unknown or controversial (for example, any of the list of 189 hazardous air pollutants [HAPs] listed in the 1990 Clean Air Act Amendments).
- If the project is viewed as "precedent setting" by the federal land manager, not necessarily in terms of air quality but for any element of the environment.
- If the project by itself would not produce significant impacts but is associated with related projects that, taken together, would produce significant impacts. Significance cannot be avoided by terming an activity "temporary" or by breaking it down into smaller component parts.
- If the project or activity emits air pollutants and is located near historical or cultural resources, parks or campgrounds, vistas, high-use recreational areas, private inholdings, prime farmlands, wetlands, wild and scenic rivers, wilderness areas, scientific research areas, or other ecologically sensitive areas.

- If the project emits air pollutants and is located in or near (within 10 miles of) a designated nonattainment or maintenance area.

- If the project will produce a significant amount of raw material whose primary use would reasonably be expected to produce significant air pollution emissions. Examples include coal or other fossil fuel operations and firewood sales.

In practice, nearly every project or activity that produces emissions of air pollutants, whether regulated or nonregulated, would be covered by one or more of these criteria. Therefore, the only circumstances in which air quality should not be considered in an EA or EIS is if the project, by itself or in combination with other projects, would not produce measurable quantities of any pollutant, including dust.

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Chapter 1
Introduction

Welcome to the USDA Forest Service NEPA Air Quality Desktop Reference! This document is designed to assist Forest Service air quality staff in preparing and reviewing air quality analyses, particularly for environmental assessments (EAs) and environmental impact statements (EISs), in a manner consistent with the National Environmental Policy Act (NEPA).

The user of this document is assumed to have some fundamental knowledge of air quality rules and regulations and a working knowledge of the NEPA process. The objective of this document is to provide a framework for incorporating air quality issues and concerns into the NEPA process. Special attention is given to presenting the methods for estimating air pollutant emissions from various Forest Service projects and activities.

Need for This Document

The Forest Service has recognized that, within the agency, there is a general lack of understanding of air quality issues and concerns and a corresponding lack of proficiency in addressing these issues in EAs and EISs. In the past, this has resulted in inadequate assessments–even complete omissions–of air quality issues in NEPA documents. The recent promulgation of the General Conformity Rule (58 Code of Federal Regulations [CFR] 63214) by the U.S. Environmental Protection Agency (EPA), the ongoing revisions to National Forest management plans, and the use of integrated resource management principles all demonstrate the need for an improvement in the air quality analysis capabilities within the Forest Service. Development of a standard desk reference for all Forest Service personnel is one step toward this goal.

Scope of Document

The body of this document is divided into six chapters:

- Chapter 1: Introduction to the desk reference, including the purpose and scope of the document and the intended audience.

- Chapter 2: Overview of the NEPA process, including a description of the key elements of a NEPA air quality analysis. Chapter 2 also provides guidance on how to obtain detailed information on the air quality regulations in each state.

- Chapter 3: Comprehensive list of emissions sources for Forest Service projects and activities, and detailed descriptions of calculation methods available for

estimating emissions from Forest Service projects and activities, including equations and examples where appropriate. Chapter 3 includes a summary of mitigation measures available for reducing emissions from these projects and activities. The emphasis of this chapter is on the emissions of "criteria" pollutants (such as sulfur dioxide, nitrogen oxides, and particulate matter), but the chapter also includes a discussion of the potential for emissions of the 189 hazardous air pollutants identified in the 1990 Clean Air Act Amendments.

- Chapter 4: Synopsis of available modeling options, organized by project or activity.

- Chapter 5: Synopsis of ambient monitoring techniques available to assess background conditions and changes to those conditions from proposed projects, also organized by project or activity.

- Chapter 6: References.

Chapter 2
The NEPA Process and Air Quality

This chapter provides an overview of the NEPA process and a framework for incorporating air quality issues and concerns into the process. The chapter is divided into two major sections. The first summarizes the regulatory framework for addressing air quality issues and concerns in the NEPA process. It includes a summary of the National Environmental Policy Act, the Clean Air Act, and various air resource management policies and guidelines within the Forest Service. This is not intended to be an exhaustive review of legislation and policy; for more detailed information on NEPA, the reader is encouraged to review Fogleman (1990) or similar books on the subject.

The second section presents some general guidelines for preparing a NEPA air quality analysis. Subsections include guidelines for determining when air quality issues and concerns are considered "significant" and therefore required to be included in the NEPA analysis, the documentation requirements in NEPA (i.e., when an EIS is required and an EA would be acceptable), the appropriate level of detail to include in a NEPA air quality analysis, and basic steps in preparing a NEPA air quality analysis. Also included is a discussion of the role of the Section 309 Review Committee in the NEPA review process.

Regulatory Framework for NEPA Air Quality Analyses

The National Environmental Policy Act of 1969

Overview of NEPA

The National Environmental Policy Act (NEPA) was signed into law on January 1, 1970. It is our nation's basic charter for the protection of the environment. NEPA was designed to do the following:

> "encourage productive and enjoyable harmony between man and his environment . . .promote efforts which will prevent or eliminate damage to the environment and biosphere and stimulate the health and welfare of man. . .enrich the understanding of the ecological systems and natural resources important to the nation" (National Environmental Policy Act)

NEPA is broad. It applies to all federal agencies and to every major action taken by the agencies that significantly affects the quality of the human environment. NEPA supplements all statutes not in conflict with it. Not only does NEPA give federal agencies the power to consider the environmental effects of their proposed actions, it requires them to consider these impacts before implementing a plan.

NEPA is general in its scope and wording. Accordingly, it has served more as a catalyst for the development of a "common law" of NEPA rather than as a single, encompassing statement of law. Well over one thousand judicial decisions involving NEPA have been published since its enactment. The interpretation of NEPA, and its application for federal agencies, extends far beyond the written statute.

Scope

NEPA is a procedural, not a substantive, law. Standards are set in other laws such as the Clean Air Act and the Endangered Species Act. NEPA does not prohibit activities or projects, but establishes the decision-making process.

NEPA has two titles. Title I contains a declaration and a mandate for the federal government. Title II established the Council on Environmental Quality (CEQ) within the Executive Office of the President.

In 1978, the CEQ issued the regulations for implementing the procedural provisions of NEPA. These CEQ regulations are listed in 40 Code of Federal Regulations Parts 1500-1508.

Title I of NEPA is in turn divided into two sections. Section 101 contains a broad declaration of policy (stated above). Section 102 contains NEPA's action-enforcing or procedural requirements. These procedures, which are designed to ensure that environmental protection is considered by agencies, require a strict standard of compliance. The procedure that has become the focal point of NEPA is preparation of a detailed statement of impacts to accompany every report on proposals for major federal actions significantly affecting the human environment. The detailed statement, known as an environmental impact statement (EIS), must include an analysis and discussion of the following elements:

- The environmental impacts of the proposed action
- Any adverse environmental effects that cannot be avoided if the proposal is implemented
- Alternatives to the proposed action
- The relationship between local short-term uses of man's environment and the maintenance and enhancement of long-term productivity
- Any irreversible and irretrievable commitments of resources that would be involved in the proposed action if it is implemented

The U.S. Supreme Court (Baltimore Gas & Electric Company v. Natural Resources Defence Council, Inc., 462 U.S. 87, 97 [1983]) has described NEPA as having two major purposes or aims. The first is to place "upon an agency the obligation to *consider* every significant aspect of the environmental impact of a proposed action." The second is to ensure "that the

agency will *inform* the public that it has considered environmental concerns in its decision making process." This consideration of *every significant aspect of the environmental impact* must include, when appropriate, an analysis of direct and indirect air quality impacts.

First and foremost, agencies must consider every significant aspect of the environmental impact that might result from a proposed action, and inform the public of its findings. Understanding this concept (the "Twin Aims of NEPA") is the key to an adequate analysis of effects. Secondly, it is important to understand the relationship of NEPA to environmental effects because it defines the scope of the analysis.

General Guidance

Accurate scientific analyses, input from agencies and experts, and public scrutiny are essential for implementing NEPA. NEPA documents must concentrate on the issues that are truly significant to the action in question, rather than simply amassing needless detail. NEPA's purpose is not to generate paperwork–even excellent paperwork–but to support important decisions. The NEPA process is designed to help public officials make decisions that are based on an understanding of the potential environmental consequences and take actions that protect, restore, and enhance the environment.

Clean Air Act and Amendments

Overview of the Act

The Clean Air Act (CAA), passed in 1963 by the U.S. Congress and amended several times, is the primary legal instrument for air resource management. The Clean Air Act requires EPA to, among other things, identify and publish a list of common air pollutants that could endanger public health or welfare. These commonly encountered pollutants, referred to as "criteria pollutants," are required to be listed by EPA along with the results of studies documenting the health effects of various concentrations of each pollutant. For each criteria pollutant, EPA is required to designate a concentration level above which the pollutant would endanger public health or welfare. For each criteria pollutant, the EPA must establish a national ambient air quality standard (NAAQS) to protect human health and welfare. The standards are supported by "criteria" documents containing the most recent scientific knowledge regarding the effects of each pollutant. These standards are to be reviewed by EPA at least every 5 years and adjusted or revised to reflect the latest scientific evidence on the effect of that pollutant.

Criteria Pollutants and Standards

To date, NAAQSs have been established for six criteria pollutants: sulfur dioxide (SO_2), inhalable particulate matter (PM_{10}), carbon monoxide (CO), ozone (O_3), nitrogen oxides (NO_x), and lead (Pb) (see Table 2-1). There are exceptions, but generally these standards are not to be violated anywhere within the United States. If they are violated in an area, the area may be designated a "nonattainment area" (because the area does not "attain" the NAAQS

for that pollutant), and that state is required to submit an implementation plan to bring the area back into compliance with the standards. Under NEPA, the Forest Service is required to disclose the impacts of its management activities on the NAAQSs.

The particulate matter standard originally promulgated in 1971 measured total suspended particulate matter (TSP). Later studies indicated that most of the adverse health effects from particulate matter were caused by the fine, inhalable particles; therefore, the particulate matter standard was revised to measure particulate matter smaller than 10 micrometers in aerodynamic diameter, or PM_{10}. At present, these standards are being revised to measure particulate matter less than 2.5 microns in diameter.

Table 2-1
National Ambient Air Quality Standards

Pollutant	Averaging Period	Primary NAAQS	Secondary NAAQS
Carbon monoxide (CO)	8 hour	9 ppm (10,000 $\mu g/m^3$)	9 ppm (10,000 $\mu g/m^3$)
	1 hour	35 ppm (40,000 $\mu g/m^3$)	35 ppm (40,000 $\mu g/m^3$)
Lead (Pb)	Calendar quarter	1.5 $\mu g/m^3$	1.5 $\mu g/m^3$
Ozone (O_3)	1 hour	0.12 ppm (235 $\mu g/m^3$)	0.12 ppm (235 $\mu g/m^3$)
Nitrogen dioxide (NO_2)	Annual arithmetic mean	0.053 ppm (100 $\mu g/m^3$)	0.053 ppm (100 $\mu g/m^3$)
Sulfur dioxide (SO_2)	Annual arithmetic mean	0.03 ppm (80 $\mu g/m^3$)	None
	24 hour	0.14 ppm (365 $\mu g/m^3$)	None
	3 hour	None	0.5 ppm (1,300 $\mu g/m^3$)
Inhalable particulate matter, PM_{10}	Annual arithmetic mean	50 $\mu g/m^3$	50 $\mu g/m^3$
	24 hour	150 $\mu g/m^3$	150 $\mu g/m^3$

Notes: ppm = Parts per million.
$\mu g/m^3$ = Micrograms of pollutant per cubic meter of air.
Arithmetic mean = The sum of a set of *n* terms, divided by *n*.

Two types of NAAQSs are required by the CAA, a primary standard and a secondary standard. Primary NAAQSs are designed to protect public health, allowing for an adequate margin of safety. The primary NAAQSs have been set at levels low enough to protect people with preexisting illnesses, the young, or people with conditions that might be aggravated by such pollutants. The cost and technical feasibility of attaining such levels are not to be considered.

Secondary standards are designed to protect human welfare from any known or anticipated adverse effects of the criteria pollutant on the soil, water, crops, animals, structures, or other property. The secondary standards are generally more stringent than the primary standards. This is because some plant species are more sensitive to pollution concentrations than humans. For example, the 3-hour average secondary SO_2 standard is more stringent than the 24-hour average primary SO_2 standard. This secondary standard was established to prevent exposure to any concentration of emissions, however brief, from injuring vegetation.

State Implementation Plans

The CAA requires states to prepare detailed state implementation plans (SIPs) that specify how the primary and secondary NAAQS will be achieved and maintained. The development of the SIPs begins by dividing each state into appropriate air quality airsheds, known as air quality control regions (AQCRs). Each state must demonstrate that the measures, rules, and regulations contained in the SIP are adequate to meet and maintain the NAAQSs in each AQCR. In nonattainment areas, the SIP must provide for *"reasonable further progress"* (Clean Air Act) in achieving annual incremental reductions in relevant air pollutants. Additionally, the SIPs provide an accurate inventory of actual emissions of the criteria pollutant in the nonattainment area.

By statute, SIPs must contain the following elements:

- Enforceable emissions limitations
- Control measures
- Methods for monitoring ambient air quality
- Air quality modeling or analysis
- Enforcement of noncompliance
- Permit programs for stationary sources
- Local government participation
- Sufficient staff and funding to implement the SIP provisions

The ultimate effect of the SIP, regardless of the statutory plan, must be to meet the NAAQSs. Emission controls can be imposed on mobile, stationary, or area sources depending on the nature and severity of the air quality problems.

States also have the authority to include in their SIPs air quality standards that are more stringent than the federal air quality standards. Because state regulations vary greatly in complexity and intent, it is beyond the scope of this document to discuss them. Appendix A contains a list of air quality contacts in each state where detailed information might be obtained.

Once a SIP is fully approved by EPA, it is legally binding under both state and federal law and may be enforced by either government. The Forest Service is required to comply with all requirements of a SIP. Air quality staff within the Forest Service should be familiar with the detailed provisions of the SIPs in their states (or districts). The air quality contacts listed

in Appendix A might also serve as a first point of contact for information on the SIPs in each region.

SIP Conformity

The conformity section of the CAA (Section 176(c)) prohibits federal agencies from permitting, approving, providing financial assistance, or supporting in any way any activity that does not conform to a SIP. EPA has recently promulgated rules for implementing this section of the CAA for federal activities occurring within a nonattainment area. These rules are comprehensive, with specific criteria for assessing applicability, determining impacts, and involving the public before a conformity determination can be made.

One of the criteria for assessing whether an activity must undergo a full conformity analysis is whether the activity produces less than the *de minimis* (that is, threshold) emissions (in tons per year). The *de minimis* emissions for both nonattainment areas (areas currently in noncompliance with the NAAQSs) and maintenance areas (areas that were once nonattainment areas but are currently in attainment of the NAAQSs) are presented in Table 2-2. For example, assume that a prescribed burn produces 95 tons per year of particulate matter. Because the project-related PM_{10} emissions are less than the *de minimis* emission rate of 100 tons per year, the project would be considered to be in conformity with the SIP and therefore would not have to undergo additional analysis. The Forest Service is currently drafting national guidance for addressing conformity. In the meantime, individuals should contact their Regional Air Program Managers for more specific information. Conformity is a requirement that must be addressed in all NEPA documents.

In developing their general conformity rules, the EPA has tried to make the rules compatible with NEPA. It is the EPA's intention to allow agencies to use their conformity analysis for all or part of their NEPA air quality analysis if the agency finds it appropriate to do so; however, EPA has no intention of requiring that agencies replace their air quality analysis with their general conformity analysis.

New Source Performance Standards

The CAA requires EPA to set new source performance standards for some new sources based on the best available control technology (BACT). Special standards have been promulgated for more than 60 categories of stationary sources. These standards apply only to sources that are constructed, modified, or reconstructed after promulgation of the relevant standards.

Table 2-2
***De Minimis* Emission Rates for Conformity Determinations**

Pollutant	Emissions (tons/year)
Nonattainment Areas	
Ozone (VOCs or NO_x)	
"Serious" Nonattainment Area	50
"Severe" Nonattainment Area	25
"Extreme" Nonattainment Area	10
Other O_3 Nonattainment Area Outside an O_3 Transport Region	100
CO (All Nonattainment Areas)	100
SO_2 or NO_2 (All Nonattainment Areas)	100
PM_{10}	
"Moderate" Nonattainment Area	100
"Serious" Nonattainment Area	70
Pb (All Nonattainment Areas)	25
Maintenance Areas	
Ozone (NO_x Limited), SO_2, NO_2	100
Ozone (VOC Limited)	
Maintenance Area inside Transport Region	50
Maintenance Area outside Transport Region	100
CO	100
PM_{10}	100
Pb	25

Prevention of Significant Deterioration

The 1977 amendments to the Clean Air Act contained provisions for a special program–the Prevention of Significant Deterioration (PSD) Program–to prevent the growth of stationary industrial sources from causing a significant deterioration of air quality in areas that meet the NAAQSs (attainment areas). PSD regulations are not applicable in nonattainment areas; new or modified stationary sources located in these areas are subject to more stringent requirements. The PSD requirements call for careful monitoring of actual air quality conditions and placement of limits on the "increment" of clean air that can be used by industrial projects. Allowable increments have been established for both Class I and Class II (non-pristine) airsheds (see Table 2-3).

Table 2-3
PSD Increments for Class I and Class II Areas

Pollutant	Averaging Period	Allowable Increments ($\mu g/m^3$)	
		Class I	Class II
Inhalable particulate matter (PM_{10})	Annual	4	17
	24-Hour	8	30
Total suspended particulate matter (TSP)	Annual	5	19
	24-Hour	10	37
Sulfur dioxide (SO_2)	Annual	2	20
	24-Hour	5	91
	3-Hour	25	512
Nitrogen dioxide (NO_2)	Annual	2.5	25

$\mu g/m^3$ = Micrograms per cubic meter.

Visibility Protection

Visibility is an air-quality-related value that is protected in all federal Class I areas. Since 1984, states have been required to protect the visibility in national parks and wilderness areas, as mandated by the 1977 Clean Air Act Amendments. The 1977 amendments established a national goal for the "*prevention of any future and the remedying of any existing impairment of visibility in mandatory Class I federal areas which impairment results from manmade pollution.*" The regulations specifically require states to consider strategies for reducing visibility impairment from prescribed forest burning.

Reasonably Available Control Measures/Best Available Control Measures

Section 190 of the CAA requires EPA to issue technical guidance on reasonably available control measures (RACM) and best available control measures (BACM) for various activities, including prescribed silvicultural and agricultural burning. RACM and BACM techniques (note that BACM is different from BACT) can be used as mitigation measures in NEPA documentation. Each regional air resource manager should have a copy of the EPA report that evaluates BACM and RACM.

Hazardous Air Pollutants (HAPs)

The 1990 amendments include a list of 189 air pollutants that are hazardous to human health because they are known to be, or have the potential to be, carcinogenic, mutagenic, or neurotoxic, or because they cause reproductive dysfunction. The list of 189 HAPs is presented in Appendix B of this document.

Guidelines for Preparing NEPA Air Quality Analyses

Documentation Requirements in NEPA

As noted in the first part of this chapter, each agency must consider every significant aspect of the environmental impacts of a proposed action, and inform the public of the findings. Environmental assessments (EA) may be prepared to document the results of environmental analysis and to disclose environmental consequences for proposed actions that are not categorically excluded from documentation and for which the need for an EIS has not been determined. An EIS is required for major federal actions which may have a *significant effect* on the quality of the human environment.

The analysis documented in the EA may result in a finding of no significant impact (FONSI). However, if the responsible official finds that the proposed action may have a significant effect on the quality of the human environment, a notice of intent to prepare an EIS should be published. A proposed action may be categorically excluded from documentation with an EA or EIS if the action is within one of the categories listed in Forest Service Handbook (FSH) 1909.15, Section 31, and there are no extraordinary circumstances related to the proposed action. A decision memo is required to document the decision to proceed with certain categories of proposed actions; for other categories, no decision memo or project file is required.

For more information on the required documentation in a NEPA assessment, the reader should consult FSH 1909.15.

When Should Air Quality Issues Be Considered?

One of the most difficult tasks facing NEPA analysis preparers is deciding when to consider air quality issues and concerns in the EA or EIS; that is, deciding when impacts are likely to be "significant" (not to be confused with *significant effect*). "Significance" as used in NEPA requires consideration of both context and intensity. Context refers to the temporal and spatial scales of the impacts (for example, short term or long term; site-specific, local, regional, or global). Intensity refers to the severity of the impacts at these varying scales (40 CFR 1508.27).

Following are some general guidelines for considering when air quality issues and concerns are likely to be considered "significant" in the NEPA process:

- If the project is highly controversial and therefore likely to receive intense public scrutiny.
- If the proposed source is located near a Class I area.
- If public health or safety could be affected by emissions of any regulated pollutant. This essentially includes any project or activity that emits pollutants, including dust.
- If the proposed project has both positive and negative impacts. For example, prescribed burning might produce significant increases in smoke emissions in the short term, but significant decreases in smoke emissions over the long term through reductions in fuel loading and reduced hazard of large, high-intensity wildfires.
- If the project or activity produces emissions of pollutants whose health or ecological effects are unknown or controversial (for example, any of the list of 189 hazardous air pollutants [HAPs] listed in the 1990 Clean Air Act Amendments).
- If the project is viewed as "precedent setting" by the federal land manager, not necessarily in terms of air quality but for any element of the environment.
- If the project by itself would not produce significant impacts but is associated with related projects that, taken together, would produce significant impacts. Significance cannot be avoided by terming an activity "temporary" or by breaking it down into smaller component parts.
- If the project or activity emits air pollutants and is located near historical or cultural resources, parks or campgrounds, vistas, high-use recreational areas, private inholdings, prime farmlands, wetlands, wild and scenic rivers, wilderness areas, scientific research areas, or other ecologically sensitive areas.

- If the project emits air pollutants and is located in or near (within 10 miles of) a designated nonattainment or maintenance area.

- If the project will produce a significant amount of raw material whose primary use would reasonably be expected to produce significant air pollution emissions. Examples include coal or other fossil fuel operations and firewood sales.

In practice, nearly every project or activity that produces emissions of air pollutants, whether regulated or nonregulated, would be covered by one or more of these criteria. Therefore, the only circumstances in which air quality should not be considered in an EA or EIS is if the project, by itself or in combination with other projects, would not produce measurable quantities of any pollutant, including dust.

Elements of a NEPA Air Quality Analysis

The requirements for a NEPA air quality analysis are different for EAs and EISs. The requirements for an EA are (FSH 1909.15, Chapter 41.2):

- Need for proposal
- Description of alternatives
- Environmental impacts of proposed action and alternatives
- Listing of agencies and persons consulted

The requirements for an EIS are more comprehensive (FSH 1909.15, Chapter 22.3):

- Cover sheet
- Summary
- Table of contents
- Purpose of, and need for, the proposed action
- Description of alternatives, including the proposed action
- Affected environment
- Environmental consequences
- List of preparers
- List of agencies, organizations, and persons to whom copies of the statement are sent
- Index
- Appendices

The substance of either analysis is contained in the sections on purpose and need, alternatives, affected environment (EIS only), and environmental consequences. Guidance on preparing each of these sections is presented below.

Purpose and Need

The EA or EIS should briefly specify the underlying purpose and need to which the agency is responding in proposing the alternatives including the proposed action.

Alternatives

This section is the heart of the environmental impact statement. It should present the environmental impacts of the proposal and the alternatives in comparative form, thus sharply defining the issues and providing a clear basis for choice among options by the decision-maker and the public. In this section, the preparer should:

- Rigorously explore and evaluate all possible alternatives
- Objectively evaluate the relative merits of each alternative and the proposed action
- Include reasonable alternatives not within the jurisdiction of the lead agency
- Identify the agency's preferred alternative(s)
- Include the alternative of no action
- Include appropriate mitigation measures not already included in the proposed action or alternatives
- State whether or not each alternative is consistent with the Forest Plan (alternatively, the Forest Land and Resource Management Act (36 CFR 219.10(c))

Affected Environment

The EIS should succinctly describe the environment of the area or areas to be affected or affected by the alternatives under consideration. These descriptions should be no longer than necessary to understand the effects of the alternatives. Verbose descriptions should be avoided.

For air quality, the affected environment section should include the following:

- General meteorology and climatology of the area, including temperature (average and range), precipitation (average and range), predominant wind directions, wind speeds (average and range), and stagnation events (depth and duration).

- Locations of sensitive sites in the vicinity of the proposed project. Sensitive sites include Class I airsheds, residences, communities, schools, hospitals, convalescence care centers, nonattainment areas or special protection zones, recreation areas, or popular vistas.

- Background air quality and deposition rates in the vicinity of the proposed sources and receptors. Indicate patterns of air quality impairment and the

known sources of emissions that could affect the background air quality, such as industry, wood smoke from stoves or prescribed fires, urban centers (including highways and airports), or field burning.

- A discussion of applicable air quality standards and regulations.

Environmental Consequences

This section forms the scientific and analytic basis for the comparison of alternatives elsewhere in the document. The content required for an EA is somewhat different from that required for an EIS, as described below.

The subject of environmental consequences is covered throughout the CEQ regulations, but the substantive requirements are found in Section 1502.16. This section of the regulations outlines the content requirement for the section or chapter of the environmental impact statement that addresses environmental effects. Although these regulations are specific to environmental impact statements, they provide excellent guidances for considering and disclosing environmental effects in an environmental assessment too.

The discussion of environmental consequences should address potential environmental impacts of the alternatives, including (FSH 1909.15, Section 15):

- Direct effects and their significance

  Example: Increase in short-term particulate matter concentrations resulting from a proposed prescribed burning program.

- Indirect effects and their significance

  Example: Decrease in wildfire emissions produced by a reduction in overall fuel loadings following implementation of an accelerated prescribed fire burning program.

  Another Example: Increase in woodstove emissions from residential growth (or growth rates) induced by issuance of special use permit for ski area development or expansion.

- Environmental effects of alternatives and the proposed action (including cumulative effects)

  This section should include a quantitative estimate of pollutant emissions, both before and after the plan is implemented. Typically, "before" is assumed to be the current year and "after" is assumed to be the first year after full implementation of the proposed project. Impacts may be inferred from these emissions estimates. If emissions

are demonstrated to increase significantly as a result of the proposed project, dispersion modeling should be performed to quantify the magnitude and locations of the expected impacts. The modeling results should then be compared with state and federal air quality standards or published levels of acceptable change for affected air-quality-related values.

It is not acceptable to simply state that a proposed project or activity will comply with air quality standards, state implementation plans, or smoke management plans; rather, the EIS must disclose in an objective manner–either quantitatively or qualitatively–whether and how the project will comply. Similarly, it is not acceptable to state that a proposed project or activity will not occur unless or until it obtains the necessary air quality permits or approvals from the appropriate federal, state, or local regulatory agency; rather, the EIS must demonstrate whether the proposed project complies with all applicable federal, state, and local regulations and standards, and therefore whether it is likely to receive the necessary permits and approvals.

Reviewers should be aware that it is possible to demonstrate adverse impacts at air concentrations less than the National Ambient Air Quality Standards. For example, adverse impacts from SO_2 might occur at air concentations below 0.5 ppm (1,300 $\mu g/m^3$; 3-hour averaging period) in some threatened and endangered plant speciues.

- Possible conflicts between the proposed action and the objectives of federal, regional, state, and local land use plans, policies, and controls for the area of concern

- Energy requirements and conservation potential of alternatives and mitigation measures (required element; not part of air quality analysis)

- Natural or depletable resource requirements and conservation potential of alternatives and mitigation measures

  When included as part of an EIS, this section should include a description of irretrievable or irreversible commitments of resources. Descriptions of irretrievable or irreversible commitments of resources are not pertinent in an EA (in fact, they are unacceptable) because they automatically trigger the preparation of an EIS.

- Urban quality, historic and cultural resources, and the design of the built environment, including the reuse and conservation potential of various alternatives and mitigation measures

- Means to mitigate adverse environmental impacts (if not covered under 1502.14(f))

  The mitigation measures discussed in this section must cover the range of impacts of the proposal (FSH 1909.15, Sections 14.2 and 15). Measures should include such things as design alternatives that would reduce pollutant emissions, construction impacts, and aesthetic intrusion, as well as relocation assistance, possible land use controls that could be enacted, and other possible efforts. Mitigation measures must be considered even for elements of the environment, such as air, that by themselves might not be significantly affected by the proposed action. Once a project is determined to have significant environmental impacts, all of its specific impacts on the environment must be considered and mitigation measures must be developed whenever feasible.

  For air quality, mitigation measures would also include practices or control technology that either reduce emissions or modify the characteristics of the release or airflow such that air quality impacts at a particular location are reduced. An example of a mitigation measure is a restriction on prescribed burning during conditions that would carry the smoke plume toward nearby population centers.

  The analysis must identify all possible mitigating measures, even if they are outside the jurisdiction of the lead agency or cooperating agencies. In this way, the analysis will serve to notify the appropriate agencies and encourage them to implement the necessary measures.

  Unavoidable adverse impacts are those impacts that cannot be mitigated through alternative practices or controls. This element should be addressed only in an EIS. Descriptions of unavoidable adverse impacts are not pertinent in an EA (in fact, they are unacceptable) because they automatically trigger the preparation of an EIS.

Selecting the Appropriate Level of Detail in the Effects Analysis

NEPA requires analysis and disclosure of the effects which have a bearing on making a decision among reasonable alternatives. It does not stipulate that a given model or analysis technique be used. How the effects analysis is performed--and which tools are used--must be based on professional judgment, the issues at stake, and the analyst's knowledge of the source and its potential emissions. When in doubt, err on the side of providing more detailed analysis, not less. Regardless of the approach used, it is important to document the methodology, its strengths and weaknesses compared to other analysis techniques, and key assumptions used in the analysis.

The scope of predicting environmental effects can range from a basic literature review to sophisticated computer modeling. A graduated approach is recommended, starting with estimates of current and future emissions, then proceeding to more sophisticated techniques as required by the initial results. The decision to perform modeling should consider the quantity and type of emissions, the background air quality in the vicinity of the source or areas affected by emissions from the source, and the proximity to sensitive receptors. Examples for which modeling should be performed include:

- If the total emissions from the source or activity exceed the significant emission rates listed in Table 2-2 of this document (annual emissions).
- For existing sources or activities, if the future emissions of any regulated pollutant increases by more than 5 percent above the current emission rates.
- If the proposed source or activity is located within or near a "clean" background area; i.e., in an area relatively unaffected by anthropogenic emissions.
- If the source is known (or suspected) to cause or contribute to a violation of any national or state ambient air quality standard.
- If the source is known (or suspected) to cause or contribute to an exceedance of any threshold of acceptable change for sensitive receptors.
- If public concern over potential impacts from the source or activity dictates a detailed analysis.

Regardless of whether qualitative or quantitative techniques are used, the effects analysis should consist of the following steps (Jack Holcomb, *Guide for Soil/Water/Air Environmental Effects Analysis in NEPA Documents*, USDA Forest Service, Southern Region):

1. Clarify the issues
2. Review available information
3. Determine cause-and-effect relationships
4. "Bound" the effects analysis
5. Describe the existing conditions
6. Predict and interpret the results, including cumulative effects
7. Disclose the effects and document the analysis

Guidance for Preparers

To disclose likely changes in air quality and demonstrate that the proposed project will comply with air quality requirements, the air resource manager must have specialized knowledge of the following:

- Federal, state, and local air quality regulations and their application
- Ability to determine when air quality is likely to be a significant issue on a project
- Ability to estimate primary and secondary emissions from a project
- Ability to estimate impacts (either quantitative or qualitative) from a proposed project

Other guidance for preparers includes the following:

- Identify the impacts of each alternative in either quantitative or qualitative terms.
- Don't simply compare the emissions for each alternative; rather, compare the expected impacts (however, the latter may be based on evidence provided by the magnitude and change in emissions).
- Discuss what the expected impacts for each alternative mean in terms of resource integrity.
- Do not make value judgements about the impacts, such as "acceptable" or "negligible."

Section 309 Review Committees

Below is a list of the Environmental Review Coordinators for each of the EPA Regions. Each coordinator manages the staff that review NEPA documents pursuant to Section 309 of the Clean Air Act within their region. Depending on the technical content of the NEPA document, these coordinators will refer you to the most appropriate reviewer.

EPA Environmental Review Coordinators

Region 1
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Environmental Review Coordinator
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Region 2
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Region 3
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Region 4
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Region 9
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1200 Sixth Avenue
Seattle, WA 98101
Ph: 206-553-1983

Chapter 3

Evaluating Emissions from Forest Service Activities

Introduction

This chapter provides a set of methods for estimating short-term or long-term pollutant emissions from selected Forest Service activities or projects. Most of the methods presented in this chapter have been taken from the EPA's *Compilation of Air Pollution Emission Factors (AP-42)* manual, but other published sources have been used as well. This chapter does not provide methods for assessing the impacts (i.e., air concentrations, deposition fluxes) from proposed Forest Service sources or activities. The tools for evaluating air quality impacts are presented in Chapter 4, Options for Modeling.

This chapter is divided into five sections:

- Identification of Forest Service emission sources
- Techniques for estimating emissions from Forest Service projects and activities
- Supplemental emission factor information
- Where to get emissions models and databases
- Influence of meteorology on pollutant emissions

The first section presents a chart for identifying sources of emissions commonly associated with Forest Service projects and activities. The second section (including green tabs) summarizes the techniques for estimating emissions from air pollution sources commonly associated with Forest Service projects or activities. The third section provides information on selected electronic databases available for evaluating emissions. The fourth section summarizes where and how to obtain emissions models and electronic databases. The fifth and final section discusses the influence of meteorology on pollutant emissions, particularly fugitive emissions of particulate matter.

Identification of Forest Service Emission Sources

Figure 3-1 ("Key to Pollutant Sources by Forest Service Project") is provided on the following page to assist the reader in identifying emission sources that are associated with various Forest Service projects and activities. The list of sources identified for each project or activity is

not comprehensive; for ease of use, only those sources that are most closely associated with the project or activity are marked with a triangle. The reader must consider all other sources that are appropriate for the intended project, whether or not those sources have been identified in Figure 3-1.

The sources have been arranged into the following source groups (source group numbers in parentheses): Wood Combustion (3.1), Fugitive Dust (3.2), Internal Combustion Engines (3.3), Road Building (3.4), Road Materials Processing (3.5), Oil and Gas Development (3.6), and Miscellaneous (3.7).

Techniques for Estimating Emissions From Forest Service Projects and Activities

The green tabbed sections at the end of this chapter present a series of techniques for estimating emissions from sources commonly associated with various Forest Service projects or activities. Twenty individual sources have been identified, each with different methods for estimating emissions. For each identified source, the following information is presented:

- **Source of emissions data.** This section cites the source of information that provided most of the emissions information.

- **Estimating emissions.** This section describes the emissions source, the emission factor data, emission calculations, and meteorology and climatology affecting emissions. Emission factor data were provided for common air pollutants: NO_x, PM_{10}, particulate matter less than 2.5 meters in diameter ($PM_{2.5}$), SO_2, lead, carbon dioxide (CO_2), CO, and volatile organic compounds (VOCs). Emissions from hazardous air pollutants, metals and ozone were included where available. Models and databases available for evaluating emissions are also included. Information on how to obtain these models and databases is presented in "Where to Get Models and Databases" later in this chapter (see p. 3-6).

- **Mitigation.** This section describes techniques and controls designed to reduce emissions from the particular source. The effectiveness and appropriateness of each technique or control is discussed where applicable. This section also describes regulatory requirements for reducing emissions from sources of air pollution.

- **References.** This section lists literature that was used to develop each subchapter.

To find the emission estimation method for a specific source, note the chapter number assigned to each source group (located in the left-most column of Figure 3-1), and turn to

FIGURE 3-1

Key to Pollutant Sources by Forest Service Project

Chap. No.	Sources	Ecosystem Management Plans	Timber Harvest Operations	Campground Development	Road Construction	Building Construction	Ski Area Development	Ski Area Operation	Firewood Sales Programs	Agricultural Operations	Recreation Management (e.g., Visitor Centers, Campgrounds)	Oil and Gas Leasing	Mining Development and Operations
		Forest Service Activity or Project											
3.1	**WOOD COMBUSTION**												
3.1.1	Wildfire and prescribed natural fire	▲											
3.1.2	Prescribed burning	▲	▲	▲			▲						
3.1.3	Other open burning (wood residue)			▲			▲	▲	▲		▲		
3.1.4	Residential fireplaces							▲	▲		▲		
3.1.5	Residential wood stoves							▲	▲		▲		
3.2	**FUGITIVE DUST**												
3.2.1	Vehicle traffic on unpaved roads		▲	▲	▲	▲	▲				▲	▲	▲
3.2.2	Vehicle traffic on paved roads		▲		▲	▲	▲	▲			▲	▲	▲
3.2.3	Heavy construction operations (fugitive dust)			▲								▲	
3.2.4	Aggregate handling and storage piles				▲	▲							▲
3.3	**INTERNAL COMBUSTION ENGINES** (exhaust)												
3.3.1	Gasoline and diesel industrial engines (stationary)		▲		▲	▲	▲	▲			▲	▲[1]	▲
3.3.2	Motor vehicle emissions		▲	▲	▲	▲	▲	▲				▲[1]	
3.3.3	Large diesel engines (stationary)											▲[1]	▲
3.4	**ROAD BUILDING**												
3.4.1	Asphalt paving			▲	▲		▲						
3.4.2	Asphaltic concrete plants				▲								
3.5	**ROAD MATERIALS PROCESSING**												
3.5.1	Crushed stone processing				▲								
3.5.2	Sand and gravel processing				▲								
3.5.3	Ore crushing and grinding												▲
3.6	**OIL AND GAS DEVELOPMENT**												
3.6.1	Well field emissions											▲	
3.6.2	Tank farm emissions											▲	
3.7	**MISCELLANEOUS**												
3.7.1	Wind erosion of bare or vegetated soil	▲	▲							▲			

1 Example: pumping stations

ope70167.6f.c1 USDA NEPA 1/31/95

the appropriate green tab. Within each green tab, the individual sources are organized as they are in Figure 3-1.

Supplemental Emission Factor Information

In addition to the information provided in the sections on individual sources, supplemental emission factor data are also available in electronic databases, including the following:

- Factor Information Retrieval System (FIRE)
- VOC/PM Speciation Data System (SPECIATE)

Each of these electronic databases is described below. Information on how to obtain these databases is presented later in this chapter in "Where to Get Models and Databases" (see p. 3-6).

Factor Information Retrieval Data System (FIRE)

Factor Information Retrieval (FIRE) is a database program containing EPA's recommended criteria and hazardous air pollutant emission estimation factors. FIRE includes information about industries and their emitting processes, the chemicals emitted, and the emission factors. This database is composed of two primary modules: an emission factor "repository" system and an emission factor "distribution" system. The "repository system" is used to store and analyze data for the purpose of developing recommended factors for the "distribution system." This information is not distributed outside the agency. As its name implies, the distribution system provides to all users of FIRE only the best available emission factors that have been reviewed and rated by EPA. In essence, the distribution system will become an electronic version of *AP-42*.

FIRE is a user-friendly, menu-driven system with an interface patterned after Microsoft Windows®. Users can browse through records in the database or select specific emission factors. An important feature of FIRE is the user's ability to submit emission factors and data to EPA, via the system, for evaluation and inclusion in the repository system. These data will be evaluated by EPA and potentially used to revise emission factors in the distribution system.

The FIRE data system is distributed on one 3.5-inch floppy diskette, or it can be downloaded from the CHIEF bulletin board system (see "Where to Get Models and Databases," p. 3-6). The FIRE data system will require, at a minimum, the following microcomputer software and hardware configurations for an IBM®-compatible computer:

- Microsoft (MS) Disk Operating System (DOS) Version 3.3 or later
- Video graphics array (VGA) color monitor
- 512 kilobytes (KB) of available random-access memory (RAM)
- Hard disk with at least 10 megabytes (MB) of available disk storage space

VOC/PM Speciation Data System (SPECIATE)

The Volatile Organic Compound/Particulate Matter (VOC/PM) Speciation Data System (SPECIATE) contains about 700 total profiles for various stationary point and area source categories. This database also includes profiles on mobile sources. There are 363 particulate matter (PM) profiles representing 23 overall source categories. Each PM profile in the system contains the following information:

- Profile name
- Profile number
- Profile data quality
- Control device identification
- Reference(s)
- Data source
- Source Classification Code (SCC)
- Mass fraction data
- Species identification
- Particulate size range
- Uncertainty associated with particulate size range
- Date

Currently, there are about 339 VOC profiles contained in the database system. These profiles span approximately 31 industrial and nonindustrial source categories. Each VOC profile contains the following information:

- Profile name
- Profile number
- Profile data quality
- Control device identification
- Reference(s)
- Data source
- SCC
- Chemical species
- Date

A pollutant synonym search function is available in the SPECIATE system. Chemical synonyms were developed for as many SPECIATE pollutants as possible using existing data in the Registry of Toxic Effects of Chemical Substances (RTECS). A chemical synonym computer file was created to allow the user to search and locate a specific pollutant by more than one name, if necessary. Up to five chemical synonyms have been retained for each pollutant, where applicable.

In addition to the VOC/PM profiles based on some level of test data, this database also contains VOC/PM profile assignments for all SCCs in the Aerometric Information Retrieval System (AIRS) and additional area source codes used in the National Acid Precipitation

Assessment Program (NAPAP). Ideally, a profile would be needed to represent each one of these categories; however, the number of categories to be characterized is much larger than the available profiles. Therefore, profile assignments that involve linking a VOC profile to a source category that does not have an original profile assignment have been developed using engineering judgment.

For several SCCs, profile assignments using engineering judgment were not possible; however, in such cases, industry-specific average profiles were developed. These profiles were developed from original profiles representing other SCCs within the same industry group. The industry-specific average profiles are intended for use only if there is no other information available. In addition, "zero" profiles, which are an overall average based on all the VOC and PM profiles in the database, were developed. These profiles are intended for use only as default profiles, to represent those SCCs characterized by "zero" or "negligible" VOC and PM emission factors.

The SPECIATE system is currently available only in a computerized database format that is distributed on floppy diskettes or can be downloaded from the CHIEF bulletin board system. The SPECIATE system will require, at a minimum, the following microcomputer hardware configuration for DOS machines:

- 640 KB of RAM
- Fixed disk with at least 5 MB of storage

Where to Get Models and Databases

The models and databases described in this chapter introduction and the following subchapters are available from two primary sources:

- National Technical Information Service (NTIS)
- EPA Technology Transfer Network (TTN)

Each of these sources is described below.

National Technical Information Service (NTIS)

The emissions models, databases, and user's documentation presented in this chapter are available from the National Technical Information Service (NTIS), a branch of the U.S. Department of Commerce. NTIS is the central distribution center for the sale of U.S.- and foreign-government-sponsored research, development, engineering, and business reports. Documentation and code can be obtained by contacting the following:

Computer Products
National Technical Information Service (NTIS)
U.S. Department of Commerce
Springfield, VA 22161
Phone: (703) 487-4650

Technology Transfer Network (TTN)

Models and databases are also available from the EPA Office of Air Quality Planning and Standards Technology Transfer Network (TTN). The TTN is an electronic bulletin board system (BBS) that is used to facilitate communications and provide information to all persons involved in air pollution control and prevention activities. To access the TTN the following computer equipment is needed:

- Computer
- 1200-, 2400-, or 9600-baud modem (9600 baud recommended)
- Communication software

Once the computer hardware is set up, the communications program must be installed and set up with the following parameters:

Telephone number:	(919) 541-5742 (1200/2400-baud modem) (919) 541-1447 (9600-baud modem)
Data Bits:	8
Parity:	None
Stop Bit:	1
Emulation:	VT100 (Optional; required to display personal computer [PC] graphics and colors if your system supports it)
Duplex:	Full

With these settings installed on the computer system, the TTN can be accessed. The only cost for using the TTN is the telecommunication charges.

The models and databases discussed in this section are available from two BBSs on the TTN: the Clearinghouse for Inventories and Emission Factors (CHIEF) and the Office of Mobile Sources (OMS). Announcements and new information are summarized in the "Alerts" area on each bulletin board, allowing the user to quickly review the latest developments. Following are brief descriptions of these bulletin boards.

CHIEF

The CHIEF BBS provides access to tools for estimating emissions of air pollutants and performing air emission inventories. CHIEF serves as EPA's central clearinghouse for the latest information on air emission inventories and emission factors. Emission estimation

databases, newsletters, announcements, and guidance on performing inventories are also available on CHIEF.

OMS

The OMS BBS provides the user with information pertaining to mobile source emissions. The information provided in this BBS includes rule making and reports resulting from the Clean Air Act, vehicle emissions models (such as MOBILE5 and PART5), and other relevant mobile source emissions documents.

Influence of Meteorology on Pollutant Emissions

Fugitive emissions of particulate matter are strongly affected by local meteorological and climatological conditions. The primary meteorological and climatological variables that affect emissions are wind and precipitation. Both variables vary with the geographic location, season, and weather. In general, emissions from unenclosed sources (principally fugitive dust sources) can be expected to be greater during high wind conditions. Emissions from process emission sources and fugitive dust sources are typically greater in arid regions and during the summer months when relative humidities are low and wind speeds are high.

Some emission factor data provided in the green tabbed sections can be corrected using local meteorology or climatology. Other factors, however, were developed using data collected during specific meteorological or climatological conditions. When assessing emissions using these factors, note the conditions under which the data were collected. These conditions may not be the same as those influencing the project emissions being evaluated. When presenting the estimates of emissions for a project, discuss how the differences between the project's meteorology and climatology may affect the estimated emissions.

3.1.1 Wildfire and Prescribed Natural Fire

13.1 Wildfires And Prescribed Burning

13.1.1 General[1]

A wildfire is a large-scale natural combustion process that consumes various ages, sizes, and types of flora growing outdoors in a geographical area. Consequently, wildfires are potential sources of large amounts of air pollutants that should be considered when trying to relate emissions to air quality.

The size and intensity, even the occurrence, of a wildfire depend directly on such variables as meteorological conditions, the species of vegetation involved and their moisture content, and the weight of consumable fuel per acre (available fuel loading). Once a fire begins, the dry combustible material is consumed first. If the energy release is large and of sufficient duration, the drying of green, live material occurs, with subsequent burning of this material as well. Under proper environmental and fuel conditions, this process may initiate a chain reaction that results in a widespread conflagration.

The complete combustion of wildland fuels (forests, grasslands, wetlands) require a heat flux (temperature gradient), adequate oxygen supply, and sufficient burning time. The size and quantity of wildland fuels, meteorological conditions, and topographic features interact to modify the burning behavior as the fire spreads, and the wildfire will attain different degrees of combustion efficiency during its lifetime.

The importance of both fuel type and fuel loading on the fire process cannot be overemphasized. To meet the pressing need for this kind of information, the U. S. Forest Service is developing a model of a nationwide fuel identification system that will provide estimates of fuel loading by size class. Further, the environmental parameters of wind, slope, and expected moisture changes have been superimposed on this fuel model and incorporated into a National Fire Danger Rating System (NFDRS). This system considers five classes of fuel, the components of which are selected on the basis of combustibility, response of dead fuels to moisture, and whether the living fuels are herbaceous (grasses, brush) or woody (trees, shrubs).

Most fuel loading figures are based on values for "available fuel", that is, combustible material that will be consumed in a wildfire under specific weather conditions. Available fuel values must not be confused with corresponding values for either "total fuel" (all the combustible material that would burn under the most severe weather and burning conditions) or "potential fuel" (the larger woody material that remains even after an extremely high intensity wildfire). It must be emphasized, however, that the various methods of fuel identification are of value only when they are related to the existing fuel quantity, the quantity consumed by the fire, and the geographic area and conditions under which the fire occurs.

For the sake of conformity and convenience, estimated fuel loadings estimated for the vegetation in the U. S. Forest Service Regions are presented in Table 13.1-1. Figure 13.1-1 illustrates these areas and regions.

3.1.1 Wildfires and Prescribed Natural Fire

Source of Emissions Data

The following information was obtained from:

Peterson, Janice L. *Guidelines for Preparing a NEPA Air Quality Analysis.* (personal communication).

U.S. Environmental Protection Agency. 1985 and ff. *Compilation of Air Pollutant Emission Factors, Volume I: Stationary Point and Area Sources* (Fourth Edition). Section 11.1.

Estimating Emissions

General Description.[1] Wildfires, including prescribed natural fires, are a natural combustion process that consumes various ages, sizes, and types of flora growing outdoors in a geographical area. Wildfires are a potential source of large amounts of air pollutants.

The size, intensity, and occurrence of a wildfire depend directly on variables such as meteorological conditions, the species of vegetation involved and their moisture content, and the weight of consumable fuel per acre (available fuel loading). In the beginning stages of a wildfire, the dry combustible material is consumed first. As the wildfire progresses, the drying of green, live material occurs, with subsequent burning of this material as well. Under proper environmental and fuel conditions, this process may initiate a chain reaction that results in a widespread conflagration.

The complete combustion of wildland fuels (e.g., forests, grasslands, wetlands) requires a heat flux (i.e., temperature gradient), adequate oxygen supply, and sufficient burning time. The size and quantity of wildland fuels, meteorological conditions, and topographic features interact to modify the burning behavior as the fire spreads, and the wildfire will attain different degrees of combustion efficiency during its lifetime.

Fuel Loading Data[1]. Estimates of wildfire emissions requires detailed information on the *available* fuel loading; that is, the amount of combustible material consumed by wildfire under specific weather conditions. This should not be confused with either *total* fuel loading (that is, all the combustible material that would burn under the most severe weather and burning conditions) or *potential* fuel loading (that is, the larger woody material that remains even after a high-intensity wildfire).

Available fuel loadings may be estimated in one of several ways:

- Use of fuels inventory data when available (or alternatively, the National Fire Danger Rating System fuel model profiles) coupled with experience-based estimates of the percentage fuel consumption under specific fuel moisture and weather conditions.

- Use of fuels inventory data (or alternatively, the National Fire Danger Rating System fuel model profiles) coupled with model estimates of fuel consumption under specific fuel moisture and weather conditions. Available models include the First Order Fire Effects Model (FOFEM) and the CONSUME model[2].

- Use of historical wildfire fuel consumption data for different Forest Service regions. These estimates are presented in Table 3.1.1-1. Caution should be exercised in the use of these data; they are based on 1971 estimates of fuel consumption only, and should probably be used only if local fuel loading data are unavailable.

Table 3.1.1-1
Regional Estimates of Available Fuel Loading[a]

Forest Service Region	Available Fuel Loading	
	(tons/acre)	(Mg/hectare)[b]
Region 1 - Northern	60	135
Region 2 - Rocky Mountain	30	67
Region 3 - Southwestern	10	22
Region 4 - Intermountain	18	40
Region 5 - California	18	40
Region 6 - Pacific Northwest	60	135
Region 8 - Southern	9	20
Region 9 - Eastern	11	25
Region 10 - Alaska	16	36
All Regions	17	38

[a] Source: USEPA (1985), AP-42, 1971 fuel consumption only
[b] Fuel loading consumed in wildfire per unit area
[c] Mg = megagram (one million grams)

Emission Factor Data.[1] It has been hypothesized, but not proven, that the emission factors for wildfire (i.e., the mass of pollutants emitted per unit mass of fuel consumed) are directly proportional to the intensity and direction of the wildfire (relative to the wind), and indirectly proportional to the rate of fire spread. Logistical problems (such as size of the burning area) and difficulties in safely situating personnel and equipment close to the fire has limited the collection of reliable emissions data from wildfires.

The only published data on wildfire emission factors was based on laboratory burning experiments. These data are presented in Table 3.1.1-2 and -3. These emission factors are not vegetation or regionally specific, and appear to be based primarily on flaming combustion (as a opposed to smoldering combustion). Because these data are based on laboratory scale combustion experiments, substantial errors may result if they are used to calculate actual wildfire emissions.

Darold Ward of the USDA Forest Service Intermountain Fire Research Laboratory in Missoula, Montana (406/329-4866) has compiled some wildfire emission factor data for some western forest types. These estimates are based on direct sampling of air in the vicinity of wildfires coupled with estimates of fuel consumption.

Table 3.1.1-2
Emission Factors By Forest Service Region (English Units)a

Forest Service Region	Emission Factors (lbs/ton)			
	Total PM	CO	VOC[b]	NO_x
All Regions	16.5	140	24	4

[a] Source: USEPA (1985), AP-42
[b] As methane

Table 3.1.1-3
Emission Factors By Forest Service Region (Metric Units)a

Forest Service Region	Emission Factors (kg/Mg)			
	Total PM	CO	VOC[b]	NO_x
All Regions	8.5	70	12	2

[a] Source: USEPA (1985), AP-42
[b] As methane

Emission Calculations. The total pollutant emissions for wildfire are calculated using the following equation:

$$E = EF * L * A$$

where
- E = Total emissions of pollutant (pollutant mass; tons)
- EF = Emission factor of pollutant (mass of pollutant emitted per mass of forest fuel consumed; lbs/ton)
- L = Fuel consumed (mass of fuel consumed per unit area of land burned; tons/acre)
- A = Land area burned (acres)

Example

A wildfire in the Pacific Northwest burns 24,710 acres and consumes an average of 60 tons of woody fuel per acre. The total estimated particulate matter emissions from this wildfire are:

$$E = \left(16.5 \frac{lbs\ PM}{ton\ fuel}\right) \cdot \left(60 \frac{ton\ fuel}{acre}\right) \cdot (24{,}710\ acres) \cdot \left(\frac{1\ ton}{2{,}000\ lbs}\right)$$

$$= 12{,}231\ tons\ PM\ emitted$$

Hazardous Air Pollutants, Trace Elements, and Ozone. Wildfires emit large amounts of volatile organic compounds (VOCs) and nitrogen oxides, both precursors of the photochemical oxidant ozone. In remote parts of the United States, the formation of ozone is limited primarily by the availability of NO_x; vegetation is a significant source of naturally occurring VOCs. In these "NO_x-limited environments," the addition of relatively small amounts of NO_x could (under the right weather conditions) lead to the formation of large amounts of ozone.

Ozone is usually not found in the vicinity of fires, but it has been shown to form by photochemical reaction in the tops of plumes[3]. Formation of ozone appears to be limited by penetration of light into the plume; as the plume becomes less dense, ozone concentrations become greater relative to smoke density. Consequently, a fire may contribute a significant fraction to the total ozone load at downwind locations. If the plume comes to ground, it may carry photochemically formed ozone with it. Because ozone is a significant pulmonary and vegetation oxidant, the likelihood that this event would result in high concentrations of

ground-level ozone should be considered in the NEPA air quality analysis. Such an analysis would require detailed information on the ozone concentrations at the tops of plumes, the plume dimensions and height, and the meteorological conditions in the vicinity of the fire (e.g., wind speed, atmospheric stability, mixing heights). This information could then be used in a simple Gaussian dispersion modeling analysis to show the ground-level concentrations downwind of the fire. A more refined modeling analysis would include the use of a regional photochemical model.

The most important potential for health effects from fires is from exposure to organic hydrocarbons. Several hundred compounds are emitted in smoke from wildland fires[3]. Two of the most important classes of compounds are polynuclear aromatic hydrocarbons (PAHs), and aldehydes.

PAHs are a well-known component of smoke, with some potential for causing cancer in exposured individuals. Examples of PAH compounds include benzo-c-phenanthrene, benzo-a-pyrene, and 3-methylcholanthrene. PAHs do not exist as free gases or vapor in the environment, but are adsorbed onto fine particles that are respirable. For wildland fires, the risk of cancer from PAH emissions is negligible[3].

Of the aldehydes produced in combustion, formaldehyde is the most extensively studied because of its wide use as a process chemical and as as component of adhesive resins. It is an irritant and is allergenic at low concentations. It is known to cause cancer in laboratory animals. Measurements of formaldehyde emissions from fire are not considered reliable, although order-of-magnitude estimates have been constructed from the scant data that exist. Between 1 and 7 grams of formaldehyde per kilogram of fuel consumed is reasonable, with accompanying estimates of 0.5-1 grams per kilogram of acetaldehyde, and 0.05-0.1 grams per kilogram of acrolein[3]. For conservatism, the upper end of each range should be used in any modeling analysis or risk assessment.

For more complete information on combustion products and emission estimates from wild and prescribed fire, the reader is encouraged to review Chapter 16 in *Natural and Prescribed Fire in the Pacific Northwest*[3].

Mitigation Techniques

The most effective means of controlling wildfire emissions is to prevent the occurrence of wildfires. A frequently used technique for reducing wildfire occurrence is "prescribed" or "hazard reduction" burning. This type of managed burn involves combustion of dead-and-down woody debris, litter, and some underbrush to prevent fuel buildup under controlled conditions, thus reducing the danger of a wildfire. Properly executed, controlled burning is expected to produce fewer total emissions than wildfire. The reasons for this include: (1) prescribed fires typically burn fewer acres than wildfires, (2) prescribed fires are managed under weather conditions that presents a small risk of crowning (i.e., burning through the

crowns), and (3) prescribed fires are set under carefully controlled conditions of high fuel moisture contents, which reduces the total consumption of large woody material and duff.

References

1. *Development of Emission Factors for Estimating Atmospheric Emissions from Forest Fires*, EPA-450/3-73-009, U.S. Environmental Protection Agency, Research Triangle Park, NC, October 1973.

2. Ottmar, R.D., M.F. Burns, J.N. Hall, and A.D. Hanson. 1992. *CONSUME Users Guide.* General Technical Report PNW-GTR-304. USDA Forest Service, Pacific Northwest Research Station, Portland, Oregon. (November 1992).

3. Sandberg, D.V. and F.N. Dost. 1993. Effects of prescribed fire on air quality and human health. *In:* Natural and Prescribed Fire in Pacific Northwest Forests, J.D. Walstad, S.R. Radosevich, and D.V. Sandberg, editors. Oregon State University Press, Corvallis. pp. 191-218.

3.1.2 Prescribed Burning

3.1.2 Prescribed Burning

Source of Emissions Data

The following information was obtained from:

Peterson, Janice L. *Guidelines for Preparing a NEPA Air Quality Analysis.* (personal communication)

U.S. Environmental Protection Agency. 1985 and ff. *Compilation of Air Pollutant Emission Factors, Volume I: Stationary Point and Area Sources* (Fourth Edition). Section 1.11.

Estimating Emissions

General Description.[1] Prescribed burning is a land treatment used under controlled conditions to accomplish natural resource management objectives. Prescribed fires are conducted within the limits of a fire plan and prescription that describes both the acceptable range of weather, moisture, fuel and fire behavior parameters and the ignition method to achieve the desired effects. Prescribed fire is a cost-effective and ecologically sound tool for forest, range, and wetland management. Its use reduces the potential for destructive wildfires and thus has the potential to maintain long-term air quality. Also, this practice removes logging residues, controls insects and disease, improves wildlife habitat and forage production, increases water yield, maintains natural succession of plant communities, and reduces the need for pesticides and herbicides. The major air pollutant concern is the smoke produced by prescribed fire.

Emission Factor Data.[2-13] Smoke from prescribed fires is a complex mixture of carbon, tars, liquids and different gases. This open combustion source produces particles of widely ranging size, depending to some extent on the rate of energy release of the fire. For example, total particulate matter and particulate matter less than 2.5 micrometers mean diameter by mass are produced in different proportions, depending on rates of heat release by the fire[2]. This difference is greatest for the highest intensity fires, where particle volume distribution is bimodal, with peaks near 0.3 micrometers and exceeding 10 micrometers[3]. Particles over about 10 microns, probably of ash and partially burned plant matter, are entrained by the turbulent nature of high-intensity fires.

In discussing prescribed burning, the combustion process is divided into preheating, flaming, glowing, and smoldering phases. The different phases of combustion greatly affect the amount of emissions produced[5-7]. The preheating phase seldom releases significant quantities of material to the atmosphere. Glowing combustion usually is associated with the burning of large concentrations of woody fuels such as logging residue piles. The smoldering combustion phase is a very inefficient and incomplete combustion process that emits pollutants at a much higher ratio to the quantity of fuel consumed than does the flaming combustion of similar materials.

The amount of fuel consumed depends on the moisture content of the fuel.[8-9] For most fuel types, consumption during the smoldering phase is greatest when the fuel is driest. When lower layers of the fuel are moist, the fire usually is extinguished rapidly.[10]

The major pollutants from wildland fires are particulate matter (PM), carbon monoxide (CO), and volatile organic compounds (VOCs). Oxides of nitrogen (NO_x) are emitted at rates of from 1 to 4 grams per kilogram burned, depending on combustion temperatures. Emissions of sulfur oxides are negligible.[11-12]

Particulate matter emissions depend on the mix of combustion phase, the rate of energy release, and the type of fuel consumed. All of these elements must be considered in selecting the appropriate emission factor for a given fire and fuel situation. In some cases, models developed by the U.S. Forest Service have been used to predict particulate matter emission factors and source strength.[13] These models address fire behavior, fuel chemistry, and ignition technique, and they predict the mix of combustion products. There is insufficient knowledge at this time to describe the effect of fuel chemistry on emissions.

Table 3.1.2-1 presents emission factors from various pollutants, by fire and fuel configuration. Evaluators should use the "flaming" and "smoldering" emission factors when fuel consumption is known by combustion phase. Otherwise, they should use the "fire-average" emission factors.

Table 3.1.2-2 gives emission factors for prescribed burning by geographical area within the United States. Estimates of the percent of total fuel consumed by region were compliled by polling fire and fuels specialists from the Forest Service. The emission factors are fire-averages and can vary by as much as 50 percent with different fuel and fire conditions.

The regional emission factors in Table 3.1.2-2 should be used only for general planning purposes. Regional averages are based on estimates of the acreage and vegetation type burned and may not reflect prescribed burning activities in a given state. Also, the regions identified are broadly defined, and the mix of vegetation and acres burned within a given state may vary considerably from the regional averages provided.

Fuel Loading Data. Local forestry officials often compile information on fuel consumption for prescribed fires and have techniques for estimating fuel consumption under local conditions. The *Southern Forestry Smoke Management Guidebook*[5] and the *Prescribed Fire Smoke Management Guide*[15] may be consulted to assist in estimating fuel consumption in different regions.

Fuel type	Combustion phase	TSP	PM10	PM2.5[1]	CO[2]
		---------pounds per ton---------			
Douglas-fir/ hemlock	Flaming	24.7	16.6	14.9	143
	Smoldering	35.0	27.6	26.1	463
	Fire-average	29.6	23.1	21.8	312
Hardwoods	Flaming	23.0	14.0	12.2	92
	Smoldering	38.0	25.9	23.4	366
	Fire average	37.4	25.0	22.4	256
Ponderosa/ lodgepole pine	Flaming	18.8	11.5	10.0	89
	Smoldering	48.6	36.7	34.2	285
	Fire-average	39.6	25.0	22.0	178
Mixed conifer	Flaming	22.0	11.7	9.6	53
	Smoldering	33.6	25.3	23.6	273
	Fire-average	29.0	20.5	18.8	201
Piled fuels	Fire-average	28.4	19.0	17.1	169
Juniper	Flaming	21.9	15.3	13.9	82
	Smoldering	35.1	25.8	23.8	250
	Fire-average	28.3	20.4	18.7	163
Sagebrush	Flaming	45.0	31.8	29.1	155
	Smoldering	45.3	29.6	26.4	212
	Fire-average	45.3	29.9	26.7	206
Chaparral	Flaming	30.9	16.5	13.6	103
	Smoldering	39.2	24.4	21.4	198
	Fire-average	35.7	21.2	18.2	159
Wildfire[3]			31.9		

[1] PM2.5 is included because it may be regulated in the future; visibility models may also require PM2.5.
[2] CO is included because it may be important to fireline workers but it dilutes rapidly and should not be a concern downwind.
[3] Wildfire emission factor included for planning associated with prescribed natural fire.

TABLE 3.1.2-1

Prescribed Fire Emission Factors for Common Western Fuel Types

Regional configuration and fuel type[a]	Percent of fuel[b]	Pollutant[c]			
		Particulate (g/kg)			CO
		$PM_{2.5}$	PM_{10}	PM	
Pacific Northwest					
Logging slash					
Piled slash	42	4	5	6	37
Douglas fir/ Western hemlock	24	12	13	17	175
Mixed conifer	19	12	13	17	175
Ponderosa pine	6	13	13	20	126
Hardwood	4	11	12	18	112
Underburning pine	5	30	30	35	163
Average for region	100	9.4	10.3	13.3	111.1
Pacific Southwest					
Sagebrush	35		9	15	62
Chaparral	20	8	9	15	62
Pinyon/Juniper	20		13	17	175
Underburing pine	15		30	35	163
Grassland	10		10	10	75
Average for region	100		13.0	17.8	101.0
Southeast					
Palmetto/gallberry	35		15	16	125
Underburning pine	30		30	35	163
Logging slash	20		13	20	126
Grassland	10		10	10	75
Other	5		17	17	175
Average for region	100		18.8	21.9	134
Rocky Mountain					
Logging slash	50		4	6	37
Underburning pine	20		30	35	163
Grassland	20		10	10	75
Other	10		17	17	175
Average for region	100		11.9	13.7	83.4
North Central and Eastern					
Logging slash	50		13	17	175
Grassland	30		10	10	75
Underburning pine	10		30	35	163
Other	10		17	17	175
Average for region	100		14	16.5	143.8

[a]Regional areas are generalized, e. g., the Pacific Northwest includes Oregon, Washington and parts of Idaho and California. Fuel types generally reflect the ecosystems of a region, but users should seek advice on fuel type mix for a given season of the year. An average factor for Northern California could be more accurately described as chaparral, 25%; underburning pine, 15%; sagebrush, 15%; grassland, 5%; mixed conifer, 25%; and Douglas fir/Western hemlock, 15%.
Dash = no data.

[b]Based on the judgment of forestry experts.

[c]Adapted from Table 11.1-3 for the dominant fuel types burned.

TABLE 3.1.2-2

Emission Factors for Prescribed Burning by U.S. Region

Emission Calculations. The total emissions of pollutants from prescribed fire may be calculated using the following equation:

$$E = EF \cdot L \cdot A$$

where	E	=	Total emissions of pollutant (mass pollutant; tons)
	EF	=	Emission factor for pollutant (mass of pollutant/mass of forest fuel consumed; lbs/ton)
	L	=	Fuel consumed (mass of fuel consumed per unit area of land burned; tons/acre)[5,15]
	A	=	Land area burned (acres)

Example

PM_{10} emissions from a prescribed fire in a hardwoods forest in the Pacific Northwest can be estimated using the following assumptions:

EF	=	12 grams PM_{10} per kilogram of fuel consumed
	=	24 lbs PM_{10}/ton of fuel consumed (note: 1 g/kg = 2 lbs/ton)
L	=	30 tons fuel/acre[5,15]
A	=	40 acres burned

$$E = \left(24 \frac{lbs\ PM_{10}}{tons\ fuel}\right) \cdot \left(30 \frac{tons\ fuel}{acre}\right) \cdot (40\ acres) \cdot \left(\frac{1\ ton}{2{,}000\ lbs}\right)$$

$$= 14.4\ tons\ PM_{10}$$

Hazardous Air Pollutants, Trace Elements, and Ozone.

Hazardous Air Pollutant and Trace Elements. The most important potential for health effects from fires is from exposure to organic hydrocarbons. Several hundred compounds are emitted in smoke from wildland fires[19]. Two of the most important classes of compounds are polynuclear aromatic hydrocarbons (PAHs), and aldehydes.

PAHs are a well-known component of smoke, with some potential for causing cancer in exposured individuals. Examples of PAH compounds include benzo-c-phenanthrene, benzo-a-pyrene, and 3-methylcholanthrene. PAHs do not exist as free gases or vapor in the environment, but are adsorbed onto fine particles that are respirable. For wildland fires, the risk of cancer from PAH emissions is negligible[19].

Of the aldehydes produced in combustion, formaldehyde is the most extensively studied because of its wide use as a process chemical and as as component of adhesive resins. It is an irritant and is allergenic at low concentations. It is known to cause cancer in laboratory animals. Measurements of formaldehyde emissions from fire are not considered reliable, although order-of-magnitude estimates have been constructed from the scant data that exist. Between 1 and 7 grams of formaldehyde per kilogram of fuel consumed is reasonable, with accompanying estimates of 0.5-1 grams per kilogram of acetaldehyde, and 0.05-0.1 grams per kilogram of acrolein[3]. For conservatism, the upper end of each range should be used in any modeling analysis or risk assessment.

Ozone. Wildfires emit large amounts of volatile organic compounds (VOCs) and nitrogen oxides, both precursors of the photochemical oxidant ozone. In remote parts of the United States, the formation of ozone is limited primarily by the availability of NO_x; vegetation is a significant source of naturally occurring VOCs. In these "NO_x-limited environments," the addition of relatively small amounts of NO_x could (under the right weather conditions) lead to the formation of large amounts of ozone.

Ozone is usually not found in the vicinity of fires, but it has been shown to form by photochemical reaction in the tops of plumes[19]. Formation of ozone appears to be limited by penetration of light into the plume; as the plume becomes less dense, ozone concentrations become greater relative to smoke density. Consequently, a fire may contribute a significant fraction to the total ozone load at downwind locations. If the plume comes to ground, it may carry photochemically formed ozone with it. Because ozone is a significant pulmonary and vegetation oxidant, the likelihood that this event would result in high concentrations of ground-level ozone should be considered in the NEPA air quality analysis. Such an analysis would require detailed information on the ozone concentrations at the tops of plumes, the plume dimensions and height, and the meteorological conditions in the vicinity of the fire (e.g., wind speed, atmospheric stability, mixing heights). This information could then be used in a simple Gaussian dispersion modeling analysis to show the ground-level concentrations downwind of the fire. A more refined modeling analysis would include the use of a regional photochemical model.

For more complete information on combustion products and emission estimates from wild and prescribed fire, the reader is encouraged to review Chapter 16 in *Natural and Prescribed Fire in the Pacific Northwest*[19].

Mitigation Techniques[17]

General. Specific mitigation techniques to reduce fire emissions include fuel loading reduction techniques, fuel consumption reduction techniques, techniques for optimizing flaming combustion, and avoidance techniques. One program that effectively combines many of these mitigation measures is seasonal burning. Spring burning, for example, results in reduced fuel consumption and emissions due to high fuel moistures. Spring also may have unstable atmospheric conditions that can lead to better smoke dispersion. Winter burning (usually only applicable to piled fuels) can result in less visibility impairment if burning takes place under conditions of natural impairment such as clouds and fog. However, inversions, which can trap smoke at ground level, tend to be more frequent in the winter.

Fuel loading reduction techniques include: improved utilization (e.g., whole tree yarding, YUM yarding), burning of unit after harvest but before new live fuels appear (applicable to broadcast burns only), and burning in the springtime prior to "green up" (again, applicable to broadcast burns only).

Fuel consumption reduction techniques include: burning concentrations of fuel rather than the entire area, burning when the 1,000-hour fuel moistures are high, burning within 4 drying months of harvest when live fuel moisture is present in large fuels, burning when the duff is wet (during winter or spring or within 5 days of significant rain), using rapid ignition techniques to achieve a high intensity fire, and further utilization of piled material prior burning (firewood, for example).

Techniques to optimize flaming combustion include: burning of piled fuels rather than broadcast burning, careful piling to reduce the amount of dirt in piles, rapid ignition to create a high intensity fire, use of "backing" fires (effective only in light fuels, such as grass, litter, and small woody ground fuels), and prompt "mopping up" of fires after the flames have diminished.

Avoidance techniques include: burning on cloudy days when the plume and residual smoke cannot be seen, during periods of atmospheric instability for better smoke dispersal, and during periods of low visitor use. In addition, real-time monitoring can be performed such that ignition can be halted if smoke impacts become greater than acceptable.

For a more detailed discussion of prescribed fire mitigation techniques, the reader is encouraged to review the U.S. EPA's *Prescribed Burning Background Document and Technical Information Document for Best Available Control Measures*[18].

Firewood Sales. If firewood sales are part of the project, and the firewood will be used in or near a PM_{10} nonattainment area, then additional mitigation measures should be considered. These measures include:

- Increase in permit fees to decrease use

- Decrease in the number of cords allowed by permit holder, or restrict the number of permits issued
- Shorten the gathering season or close the season earlier so that stored wood has more time to dry
- Provide educational materials with the cordwood permit that discusses the use of woodstoves, how to store cordwood to enhance drying, and the adverse health effects of high particulate matter concentrations
- Require that cordwood be split to less than some prescribed dimension (e.g., 6-8 inches in length) prior to removing from the forest
- Require that only dead-and-down wood be removed (i.e., no green wood)
- Permit gathering only on south-facing slopes or from aged piles

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19. Sandberg, D.V. and F.N. Dost. 1993. Effects of prescribed fire on air quality and human health. *In:* Natural and Prescribed Fire in Pacific Northwest Forests, J.D. Walstad, S.R. Radosevich, and D.V. Sandberg, editors. Oregon State University Press, Corvallis. pp. 191-218.

3.1.3 Other Open Burning

3.1.3 Other Open Burning

Source of Emissions Data

The following information was obtained from:

U.S. Environmental Protection Agency, 1995. Compilation of Air Pollutant Emission Factors, Volume I: Stationary Point and Area Sources (Fifth Edition - DRAFT). Section 2.5.

Estimating Emissions

General Description[1]. Open burning can be done in open drums or baskets, in fields and yards, and in large open dumps or pits. Materials disposed of in this manner include landscape refuse, agricultural field refuse, wood refuse, and leaves.

The following Source Classification Codes pertain to open burning of woody materials:

	Government
50100201	General Refuse
50100202	Vegetation Only
	Commercial/Institutional
50200201	Wood
50200202	Refuse
	Industrial
50300201	Wood/Vegetation/Leaves
50300202	Refuse

Emission Factor Data[1-22]. Ground-level open burning emissions are affected by many variables, including wind, ambient temperature, composition and moisture content of the debris burned, and compactness of the pile. In general, the relatively low temperatures associated with open burning increase emissions of particulate matter, carbon monoxide, and hydrocarbons and suppress emissions of nitrogen oxides. Sulfur oxide emissions are a direct function of the sulfur content of the refuse.

Organic refuse burning consists of burning field crops, wood, and leaves. Emission factors for open agricultural burning are presented in Table 3.1.3-1 as a function of refuse type and also, in certain instances, as a function of burning techniques and/or moisture content when these variables are known to significantly affect emissions.

Table 3.1.3-1 also presents typical fuel loading values associated with each type of refuse. These values can be used, along with the corresponding emission factors, to estimate emissions from certain categories of agricultural burning when the specific fuel loadings for a given area are not known.

Emission factors for leaf burning are presented in Table 3.1.3-2. For more detailed information on this subject, the reader should consult the reference cited at the end of this section.

Emission Calculations. Pollutant emissions from open burning activities can be calculated using the following equation:

$$E = EF \cdot M \quad (1)$$

where
- E = Pollutant hourly emissions, kg/hour (lbs/hour)
- EF = Emission factor, kg/Mg (lbs/ton)
- M = Amount of material burned in one hour, Mg/hour (lbs/hour)

Pollutant emissions can also be estimated using fuel loading factors. Total emissions from the affected area can be estimated using the following equation:

$$E = EF \cdot FL \cdot A \quad (2)$$

where
- E = Pollutant emissions from the affected area, kg (lbs)
- EF = Emission factor, kg/Mg (lbs/ton)
- FL = Amount of material burned in one hour, Mg/hectare (ton/acre)
- A = Affected area, hectare (acres)

Table 3.1.3-1
Emission Factors and Fuel Loading Factors for Open Burning of Agricultural Materials Emission Factor Rating: D

Refuse Category	Particulate[b]		Carbon Monoxide		VOC[c]				Fuel Loading Factors (waste production)	
					Methane		Nonmethane			
	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	Mg/hectare	ton/acre
Field Crops[d]										
Unspecified	11	21	58	117	2.7	5.4	9	18	4.5	2
Burning techniques not significant[e]										
Asparagus[f]	20	40	75	150	10	20	33	66	3.4	1.5
Barley	11	22	78	157	2.2	4.5	7.5	15	3.8	1.7
Corn	7	14	54	108	2	4	6	12	9.4	4.2
Cotton	4	8	88	176	0.7	1.4	2.5	5	3.8	1.7
Grasses	8	16	50	101	2.2	4.5	7.5	15		
Pineapple[g]	4	8	56	112	1	2	3	6		
Rice[h]	4	9	41	83	1.2	2.4	4	8	6.7	3.0
Safflower	9	18	72	144	3	6	10	20	2.9	1.3
Sorghum	9	18	38	77	1	2	3.5	7	6.5	2.9
Sugar cane[i]	2.3-3.5	6-8.4	30-41	60-81	0.6-2	1.2-3.8	2-6	4-12	8-46	3-17
Headfire Burning[j]										
Alfalfa	23	45	53	106	4.2	8.5	14	28	1.8	0.8
Bean (red)	22	43	93	186	5.5	11	18	36	5.6	2.5
Hay (wild)	16	32	70	139	2.5	5	8.5	17	2.2	1.0
Oats	22	44	68	137	4	7.8	13	26	3.6	1.6
Pea	16	31	74	147	4.5	9	15	29	5.6	2.5
Wheat	11	22	64	128	2	4	6.5	13	4.3	1.9
Backfire Burning[k]										
Alfalfa	14	29	60	119	4.5	9	14	29	1.8	0.8
Bean (red)	7	14	72	148	3	6	10	19	5.6	2.5
Hay (wild)	8	17	75	150	2	4	6.5	13	2.2	1.0
Oats	11	21	68	136	2	4	7	14	3.6	1.6
Wheat	6	13	54	108	1.3	2.6	4.5	9	4.3	1.9

Table 3.1.3-1 (Continued)

Refuse Category	Particulate[b]		Carbon Monoxide		VOC[c]				Fuel Loading Factors (waste production)	
					Methane		Nonmethane			
	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	Mg/hectare	ton/acre
Weeds										
Unspecified	8	15	42	85	1.5	3	4.5	9	7.2	3.2
Russian thistle (tumbleweed)	11	22	154	309	0.2	0.5	0.8	1.5	0.2	0.1
Tales (wild reeds)	3	5	17	34	3.2	6.5	10	21		
Vine Crops	3	5	26	51	0.8	1.7	3	5	5.6	2.5
Orchard Crops[d,l,m]										
Unspecified	3	6	26	52	1.2	2.5	4	8	3.6	1.6
Almond	3	6	23	46	1	2	3	6	3.6	1.6
Apple	2	4	21	42	0.5	1	1.5	3	5.2	2.3
Apricot	3	6	24	49	1	2	3	6	4	1.8
Avocado	10	21	58	116	3.8	7.5	12	25	3.4	1.5
Cherry	4	8	22	44	1.2	2.5	4	8	2.2	1.0
Citrus (orange, lemon)	3	6	40	81	1.5	3	5	9	2.2	1.0
Date palm	5	10	28	56	0.8	1.7	3	5	2.2	1.0
Fig	4	7	28	57	1.2	2.5	4	8	4.9	2.2
Nectarine	2	4	16	33	0.5	1	1.5	3	4.5	2.0
Olive	6	12	57	114	2	4	7	14	2.7	1.2
Peach	3	6	21	42	0.6	1.2	2	4	5.6	2.5
Pear	4	9	28	57	1	2	3.5	7	5.8	2.6
Prune	2	3	24	47	1	2	3	6	2.7	1.2
Walnut	3	6	24	47	1	2	3	6	2.7	1.2

Table 3.1.3-1 (Continued)

Refuse Category	Particulate[b]		Carbon Monoxide		VOC[c]				Fuel Loading Factors (waste production)	
					Methane		Nonmethane			
	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	Mg/hectare	ton/acre
Forest Residues[n]										
Unspecified	8	17	70	140	2.8	5.7	9	19	157	70
Hemlock, Douglas fir, cedar[p]	2	4	45	90	0.6	1.2	2	4		
Ponderosa pine[q]	6	12	98	195	1.7	3.3	5.5	11		

[a] Expressed as weight of pollutant emitted/weight of refuse material burned.
[b] Reference 12. Particulate matter from most agricultural refuse burning has been found to be in the submicrometer size range.
[c] Data indicate that VOC emissions average 22% methane, 7.5% other saturates, 17% olefins, 15% acetylene, 38.5% unidentified. Unidentified VOC are expected to include aldehydes, ketones, aromatics, cycloparaffins.
[d] References 12 - 13 for emission factors, Reference 14 for fuel loading factors.
[e] For these refuse materials, no significant difference exists between emissions from headfiring and backfiring.
[f] Factors represent emissions under typical high moisture conditions. If ferns are dried to <15% moisture, particulate emissions will be reduced by 30%, CO emission 23%, VOC emissions 74%.
[g] Reference 11. When pineapple is allowed to dry to <20% moisture, as it usually is, firing technique is not important. When headfired at 20% moisture, particulate emissions will increase to 11.5 kg/Mg (23 lb/ton) and VOC will increase to 6.5 kg/Mg (13 lb/ton).
[h] Factors are for dry (15% moisture) rice straw. If rice straw is burned at higher moisture levels, particulate emissions will increase to 14.5 kg/Mg (29 lb/ton), CO emissions to 80.5 kg/Mg (181 lb/ton), and VOC emissions to 11.5 kg/Mg (23 lb/ton).
[i] Reference 20. See Section 8.12 of AP-42, Fourth Edition, for discussion of sugar cane burning. The following fuel loading factors are to be used in the corresponding states: Louisiana, 8 - 13.6 Mg/hectare (3 - 5 ton/acre); Florida, 11 - 19 Mg/hectare (4 - 7 ton/acre); Hawaii, 30 - 48 Mg/hectare (11 - 17 ton/acre). For other areas, values generally increase with length of growing season. Use larger end of the emission factor range for lower loading factors.
[j] See text for definition of headfiring.
[k] See text for definition of backfiring. This category, for emission estimation purposes, includes another technique used occasionally to limit emissions, called into-the-wind striplighting, which is lighting fields in strips into the wind at 100 - 200 meter (300 - 600 feet) intervals.
[l] Orchard prunings are usually burned in piles. There are no significant differences in emissions between burning a "cold pile" and using a roll-on technique, where prunings are bulldozed onto the embers of a preceding fire.
[m] If orchard removal is the purpose of a burn, 66 Mg/hectare (30 ton/acre) of waste will be produced.
[n] Reference 10. NO_x emissions estimated at 2 kg/Mg (4 lb/ton).
[o] Reference 15.
[p] Reference 16.

Table 3.1.3-2
Emission Factors for Leaf Burning[a]
Emission Factor Rating: D

Leaf Species	Particulate[b]		Carbon Monoxide		VOC[c]			
					Methane		NMOC	
	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton
Black Ash	18	36	63.5	127	5.5	11	13.5	27
Modesto Ash	16	32	81.5	163	5	10	12	24
White Ash	21.5	43	57	113	6.5	13	16	32
Catalpa	8.5	17	44.5	89	2.5	5	6.5	13
Horse Chesnut	27	54	73.5	147	8	17	20	40
Cottonwood	19	38	45	90	6	12	14	28
American Elm	13	26	59.5	119	4	8	9.5	19
Eucalyptus	18	36	45	90	5.5	11	13.5	27
Sweet Gum	16.5	33	70	140	5	10	12.5	25
Black Locust	35	70	65	130	11	22	26	52
Magnolia	6.5	13	27.5	55	2	4	5	10
Silver Maple	33	66	51	102	110	20	24.5	49
American Sycamore	7.5	15	57.5	115	2.5	5	5.5	11
California Sycamore	5	10	52	104	1.5	3	3.5	7
Tulip	10	20	38.5	77	3	6	7.5	15
Red Oak	46	92	68.5	137	14	28	34	69
Sugar Maple	26.5	53	54	108	8	16	20	40
Unspecified	19	38	56	112	6	12	14	28

[a] References 18 - 19. Factors are an aritmetic average of results obtained by burning high and low moisture content conical piles, ignited either at the top or around the periphery of the bottom. The windrow arrangement was only tested on Modesto Ash, Catalpa, American Elm, Sweet Gum, Silver Maple and Tulip Poplar, and results are included in the averages for these species.

[b] The majority of particulate is submicron in size.

[c] Tests indicate that VOC emissions average 29% methane, 11% other saturates, 33% olefins, 27% other (arjomatics, acetylene, oxygenates).

The following example demonstrates the use of Equation (2).

Example

Owners of a ski lodge located in the Okanogan National Forest, Washington, are proposing an expansion of the parking facilities. The expansion is estimated to affect 10 acres of forest land. Estimate the emissions of carbon monoxide from proposed open burning of debris from this area.

Based on this information, the following parameters were selected:

EF	=	140 lbs/ton (from Table 3.1.3-1, Forest Residue-unspecified)
FL	=	70 ton/acre (from Table 3.1.3-1, Forest Residue-unspecified)
A	=	10 acres

$$E = \left(140\ \frac{lbs.}{ton}\right) \cdot \left(70\ \frac{ton}{acre}\right) \cdot 10\ acres$$

$$= 98{,}000\ lbs. = 49\ tons\ of\ CO$$

Mitigation

Emissions from organic agricultural refuse burning depend primarily on the moisture content of the refuse and, in the case of the field crops, on whether the refuse is burned in a headfire or a backfire. Headfires are started at the upwind side of a field and allowed to progress in the direction of the wind, whereas backfires are started at the downwind edge and forced to progress in a direction opposing the wind. The latter typically produces fewer emissions because backing fires in agricultural fuels have a high proportion of flaming to smoldering consumption than headfires.

Other variables such as fuel loading (how much refuse material is burned per unit of land area) and how the refuse is arranged (in piles, rows, or spread out) are also important in determining emissions.

Emissions from leaf burning are dependent upon the moisture content, density, and ignition location of the leaf piles. Decreasing the moisture content of the leaves generally decreases the emissions of carbon monoxide, hydrocarbons, and particulate matter. Decreasing the density of the piles decreases the emissions of hydrocarbons and particulate matter but has a variable effect on carbon monoxide emissions.

Emissions from leaf burning are also affected by the point of ignition on the pile. The lowest emissions generally arise from igniting a single spot on the top of the pile. The highest emissio occur when the base of the leaf pile is ignited. For windrow ignition (i.e., piling the leaves into a long row and igniting one end, allowing it to burn toward the other end), the emissions of particulate matter, hydrocarbons, and carbon monoxide are intermediate between top and bottom ignition.

References

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3.1.4 Residential Fireplaces

3.1.4 Residential Fireplaces

Source of Emissions Data

The following information was obtained from:

U.S. Environmental Protection Agency. 1985 and ff. *Compilation of Air Pollutant Emission Factors, Volume I: Stationary Point and Area Sources* (Fourth Edition). Section 1.9.

Estimating Emissions

General Description.[1,2] Fireplaces are used primarily for aesthetic effects and secondarily as a supplemental heating source in houses and other dwellings. Wood is the most common fuel for fireplaces, but coal and densified wood "logs" also may be burned. The user intermittently adds fuel to the fire by hand.

Fireplaces can be divided into two broad categories:

- Masonry (generally brick and/or stone, assembled onsite, and integral to a structure)
- Prefabricated (usually metal, installed onsite as a package with appropriate duct work)

Masonry fireplaces typically have large fixed openings to the fire bed and dampers above the combustion area in the chimney to limit room air and heat losses when the fireplace is not being used. Some masonry fireplaces are designed or retrofitted with doors and louvers to reduce the intake of combustion air during use.

Prefabricated fireplaces commonly are equipped with louvers and glass doors to reduce the intake of combustion air, and some are surrounded by ducts through which floor-level air is drawn by natural convection, heated, and returned to the room. Many varieties of prefabricated fireplaces are now available on the market. One general class is the freestanding fireplace, the most common of which consists of an inverted sheet metal funnel and stovepipe directly above the fire bed. Another class is the "zero clearance" fireplace, an iron or heavy gauge steel firebox lined inside with firebrick and surrounded by multiple steel walls with spaces for air circulation. Some zero-clearance fireplaces can be inserted into existing masonry fireplace openings, and thus are sometimes called "inserts." Some of these units are equipped with close-fitting doors and have operating and combustion characteristics similar to wood stoves (see Section 3.1.5, "Residential Wood Stoves").

Emission Factor Data.[1-13] The major pollutants of concern from fireplaces are unburned combustibles, including carbon monoxide, gaseous organic compounds, and particulate matter (such as smoke). Significant quantities of unburned combustibles are produced because

fireplaces are inefficient combustion devices, with high uncontrolled excess air rates and without any sort of secondary combustion. The latter is especially important in wood burning because of its high volatile matter content, typically 80 percent by dry weight. In addition to unburned combustibles, fireplaces emit lesser amounts of nitrogen oxides and sulfur oxides.

Hazardous air pollutants (HAPs) are a minor, but potentially important, component of wood smoke. A group of HAPs known as polycyclic organic matter (POM) includes potential carcinogens such as benzo(a)pyrene. POM results from the combination of free radical species formed in the flame zone, primarily as a consequence of incomplete combustion. Under reducing conditions, radical chain propagation is enhanced, allowing the buildup of complex organic material such as POM. The POM generally is found in or on smoke particles, although some sublimation into the vapor phase is probable.

Another important constituent of wood smoke is creosote. This tar-like substance will burn if the fire is hot enough, but at insufficient temperatures it may deposit on surfaces in the exhaust system. Creosote deposits are a fire hazard in the flue, but they can be reduced if the chimney is insulated to prevent creosote condensation or if the chimney is cleaned regularly to remove any buildup.

Fireplace emissions are highly variable and are a function of many wood characteristics and operating practices. In general, conditions that promote a fast burn rate and a higher flame intensity enhance secondary combustion and thereby lower emissions. Conversely, higher emissions will result from a slow burn rate and a lower flame intensity. Such generalizations particularly apply to the earlier stages of the burning cycle, when significant quantities of combustible volatile matter are being driven out of the wood. Later in the burning cycle, when all volatile matter has been driven out of the wood, the charcoal that remains burns with relatively few emissions.

Emission factors and their ratings for wood combustion in residential fireplaces are given in Tables 3.1.4-1 and -2.

Emission Calculations. The pollutant emissions are estimated to be a fraction of the total mass of wood combusted. Hourly pollutant emissions are calculated using the following equation:

$$E = EF * W * \frac{1\ ton}{2{,}000\ lb}$$

where E = Pollutant hourly emissions (lb of pollutant/hour)
EF = Emission factor (lb of pollutant/ton of dry wood)
W = Amount of wood burned in 1 hour (lb of dry wood/hour)

Example

Hourly emissions of particulate matter with an aerodynamic diameter of 10 micrometers (μm) or less from a residential fireplace are estimated using the following assumptions:

EF = 34.6 lb of PM_{10}/ton of dry wood
W = 10 lb of dry wood burned in 1 hour

$$E = 34.6 \frac{lb\ PM_{10}}{ton\ wood} \cdot 10 \frac{lb\ wood}{hour} \cdot \frac{1\ ton}{2000\ lb}$$

$$= 0.17 \frac{lb\ PM_{10}}{hour}$$

Table 3.1.4-1
Emission Factors for Wood Combustion in Residential Fireplaces (English Units)
(Source Classification Code: 2104008001)

Device	Pollutant	Emission Factor[a] (lb/ton)	Rating
Fireplace	PM_{10}[b]	34.6	B
	Carbon monoxide[c]	252.6	B
	Sulfur oxides[d]	0.4	A
	Nitrogen oxides[e]	2.6	C
	Carbon dioxide[f]	3400	C
	Total VOCs[g]	229.0	D
	POM[h]	1.6E-3	E[j]
	Aldehydes[k]	2.4	E[j]

[a]Units are in lb of pollutant/ton of dry wood burned.
[b]References 2, 5, 7, 13; contains filterable and condensible PM; PM emissions are considered to be 100% PM_{10} (i.e., PM with an aerodynamic diameter of 10 μm or less).
[c]References 2, 4, 5, 9, 13.
[d]References 1, 8.
[e]References 4, 9; expressed as NO_2.
[f]References 5, 13
[g]References 4 - 5, 8. Data used to calculate the average emission factor were collected by various methods. While the emission factor may be representative of the source population in general, factors may not be accurate for individual sources.
[h]Reference 2.
[j]Data used to calculate the average emission factor were collected from a single fireplace and are not representative of the general source population.
[k]References 4, 11.

Table 3.1.4-2
Emission Factors for Wood Combustion in Residential Fireplaces (Metric Units)
(Source Classification Code: 2104008001)

Device	Pollutant	Emission Factor[a] (g/kg)	Rating
Fireplace	PM_{10}[b]	17.3	B
	Carbon monoxide[c]	126.3	B
	Sulfur oxides[d]	0.2	A
	Nitrogen oxides[e]	1.3	C
	Carbon dioxide[f]	1700	C
	Total VOCs[g]	114.5	D
	POM[h]	0.8E-3	E[j]
	Aldehydes[k]	1.2	E[j]

[a]Units are in grams of pollutant/kg of dry wood burned.
[b]References 2, 5, 7, 13; contains filterable and condensible PM; PM emissions are considered to be 100% PM_{10} (i.e., PM with an aerodynamic diameter of 10 μm or less).
[c]References 2, 4, 5, 9, 13.
[d]References 1, 8.
[e]References 4, 9; expressed as NO_2.
[f]References 5, 13
[g]References 4 - 5, 8. Data used to calculate the average emission factor were collected by various methods. While the emission factor may be representative of the source population in general, factors may not be accurate for individual sources.
[h]Reference 2.
[j]Data used to calculate the average emission factor were collected from a single fireplace and are not representative of the general source population.
[k]References 4, 11.

Mitigation Techniques

Mitigation techniques for residential fireplaces usually involve improvements in heating efficiency. The greater the heating efficiency, the less wood needed to heat the structure, and the lower the total emissions. Masonry fireplaces usually heat a room by radiation. However, a significant fraction of the combustion heat is lost in the exhaust gases and through the fireplace walls. Additionally, some of the radiant heat entering the room goes toward warming the air that is pulled into the residence to make up for that drawn up the chimney. The net effect is that masonry fireplaces are usually inefficient heating devices. Indeed, in cases where combustion is poor, where the outside air is cold, or where the fire is allowed to smolder (thus drawing air into a residence without producing appreciable radiant heat energy), a net heat loss may occur in a residence using a fireplace.

Fireplace heating efficiency may be improved by a number of measures that either reduce the excess air rate or transfer back into the residence some of the heat that would normally

be lost in the exhaust gases or through fireplace walls. As noted above, such measures are commonly incorporated into prefabricated units. Consequently, the energy efficiencies of prefabricated fireplaces are slightly higher than those of masonry fireplaces.

The use of dry, cured wood should decrease the amount of smoldering consumption that occurs and thereby reduce total emissions. The emission factor for flaming consumption ranges from 20-60 percent that of smoldering consumption, depending on the fuel type and pollutant species (see Table 3.1.2-1).

Splitting wood to less than 8 inches in diameter will increase the surface area-to-volume ratio of the fuel and thereby decrease the amount of smoldering consumption that will occur.

For mitigation techniques involving firewood sales, the reader is encouraged to review Section 3.1.2 of this document.

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3.1.5 Residential Wood Stoves

see Emissions & Human Health file for "Outdoor Woodburner & Public Health"

3.1.5 Residential Wood Stoves

Source of Emissions Data

The following information was obtained from:

U.S. Environmental Protection Agency. 1985 and ff. *Compilation of Air Pollutant Emission Factors, Volume I: Stationary Point and Area Sources* (Fourth Edition). Section 1.10.

Estimating Emissions

General Description.[1,2] Wood stoves are commonly used in residences as space heaters. They are used both as the primary source of residential heat and to supplement conventional heating systems.

Five different categories should be considered when estimating emissions from wood burning devices, because of differences in both the magnitude and the composition of the emissions:

- Conventional wood stove
- Noncatalytic wood stove
- Catalytic wood stove
- Pellet stove
- Masonry heater

Among these categories, there are many variations in device design and operational characteristics.

The conventional stove category comprises all stoves without catalytic combustors not included in the other noncatalytic categories (that is, noncatalytic and pellet). Conventional stoves do not have any emission reduction technology or design features and, in most cases, were manufactured before July 1, 1986. Stoves of many different airflow designs may be in this category, such as updraft, downdraft, crossdraft, and S-flow.

Noncatalytic wood stoves are those units that do not employ catalysts but do have emission-reducing technology or features. Typical noncatalytic design includes baffles and secondary combustion chambers.

Catalytic stoves are equipped with a ceramic or metal honeycomb device, called a combustor or converter, that is coated with a noble metal such as platinum or palladium. The catalyst material reduces the ignition temperature of the unburned VOCs and CO in the exhaust gases, thus augmenting their ignition and combustion at normal stove operating temperatures. As these components of the gases burn, the temperature inside the catalyst increases to a point at which the ignition of the gases is essentially self-sustaining.

Pellet stoves are those fueled with pellets of sawdust, wood products, and other biomass materials pressed into manageable shapes and sizes. These stoves have active air flow systems and unique grate design to accommodate this type of fuel. Some pellet stove models are subject to the 1988 new source performance standards (NSPSs), while others are exempt due to a high air-to-fuel ratio (that is, greater than 35 to 1).

Masonry heaters are large, enclosed chambers made of masonry products or a combination of masonry products and ceramic materials. These devices are exempt from the 1988 NSPSs due to their weight (that is, greater than 800 kg). Masonry heaters are gaining popularity as a cleaner-burning and heat-efficient form of primary and supplemental heat, relative to some other types of wood heaters. In a masonry heater, a complete charge of wood is burned in a relatively short period of time. The use of masonry materials promotes heat transfer. Thus, radiant heat from the heater warms the surrounding area for many hours after the fire has burned out.

Emission Factor Data. The combustion and pyrolysis of wood in wood stoves produce atmospheric emissions of particulate matter, carbon monoxide, nitrogen oxides, organic compounds, mineral residues, and to a lesser extent, sulfur oxides. The quantities and types of emissions are highly variable, depending on a number of factors, including the stage of the combustion cycle. During initial burning stages, after a new wood charge is introduced, emissions (primarily VOCs) increase dramatically. After the initial period of high-burn rate, there is a charcoal stage of the burn cycle characterized by a slower burn rate and decreased emissions. Emission rates during this stage are cyclical, characterized by relatively long periods of low emissions and shorter episodes of emission spikes.

Particulate emissions are defined in this discussion as the total catch measured by the EPA Method 5H (Oregon Method 7) sampling train.[1] A small portion of wood stove particulate emissions includes "solid" particles of elemental carbon and wood. The vast majority of particulate emissions is condensed organic products of incomplete combustion equal to or less than 10 micrometers in aerodynamic diameter (PM_{10}). Although reported particle size data are scarce, one reference states that 95 percent of the particles emitted from a wood stove were less than 0.4 micrometer in size.[3]

Sulfur oxides (SO_x) are formed by oxidation of sulfur in the wood. Nitrogen oxides (NO_x) are formed by oxidation of fuel and atmospheric nitrogen. Mineral constituents, such as potassium and sodium compounds, are released from the wood matrix during combustion.

The high levels of organic compound and CO emissions are results of incomplete combustion of the wood. Organic constituents of wood smoke vary considerably in both type and volatility. These constituents include simple hydrocarbons of carbon numbers 1 through 7 (C1 - C7) (which exist as gases or which volatilize at ambient conditions) and complex low-volatility substances that condense at ambient conditions. These low-volatility condensible materials generally are considered to have boiling points below 300°C (572°F).

Emission factors and their ratings for wood combustion in residential wood stoves, pellet stoves, and masonry heaters are presented in Tables 3.1.5-1 and -2. The analysis leading to

Table 3.1.5-1
Emission Factors for Residential Wood Combustion[a] (English Units)
(Source Classification Codes)

Pollutant/EPA Certification[b]	Emission Factor Rating	Wood Stove Type			Pellet Stove Type[c] (SCC 2104008053)		Masonry Heater (SCC 2104008055)
		Conventional (SCC 2104008051)	Noncatalytic (SCC 2104008050)	Catalytic (SCC 2104008030)	Certified	Exempt	Exempt[d]
PM_{10}[e]							
Pre-Phase I	B	30.6	25.8	24.2			
Phase I	B		20.0	19.6			
Phase II	B		14.6	16.2	4.2		
All	B	30.6	19.6	20.4	4.2	8.8	5.6
Carbon monoxide[e]							
Pre-Phase I	B	230.8					
Phase I	B			104.4			
Phase II	B		140.8	107.0	39.4		
All	B	230.8	140.8	104.4	39.4	52.2	149.0
Nitrogen oxides[e]		2.8[f]		2.0[g]	13.8[g]		
Sulfur oxides[e]	B	0.4	0.4	0.4	0.4		
Carbon dioxide[h]	C				2,951.6	3,671.2	3,849.4
TOC[j]	E	48.6		24.2			
Methane	E	4.8		8.6			
TNMOC	E	43.8		15.6			

[a] Units are in lb of pollutant/ton of dry wood burned.
[b] Pre-Phase I = Not certified to 1988 EPA emission standards; Phase I = Certified to 1988 EPA emission standards; Phase II = Certified to 1990 EPA emission standards; All = Average of emission factors for all devices.
[c] Certified = Certified pursuant to 1988 NSPS; Exempt = Exempt from 1988 NSPS (i.e., air : ratio >35:1).
[d] Exempt = Exempt from 1988 NSPS (i.e., device weight >800 kg).
[e] References 6 - 14, 23 - 27, 29. PM-10 is defined as equivalent to total catch by EPA method 5H train.
[f] Rating = C.
[g] Rating = E.
[h] References 13, 24 - 27, 29.
[j] References 13, 17 - 18. TOC = Total organic compounds; TNMOC = Total nonmethane organic compounds. Data show a high degree of variability within the source population. Factors may not be accurate for individual sources.

Table 3.1.5-2
Emission Factors for Residential Wood Combustion[a] (Metric Units)
(Source Classification Codes)

Pollutant/EPA Certification[b]	Emission Factor Rating	Wood Stove Type			Pellet Stove Type[c] (SCC 2104008053)		Masonry Heater (SCC 2104008055)
		Conventional (SCC 2104008051)	Noncatalytic (SCC 2104008050)	Catalytic (SCC 2104008030)	Certified	Exempt	Exempt[d]
PM_{10}[e]							
Pre-Phase I	B	15.3	12.9	12.1			
Phase I	B		10.0	9.8			
Phase II	B		7.3	8.1	2.1		
All	B	15.3	9.8	10.2	2.1	4.4	2.8
Carbon monoxide[e]							
Pre-Phase I	B	115.4					
Phase I	B			52.2			
Phase II	B		70.4		19.7		
All	B	115.4	70.4	52.2	19.7	26.1	74.5
Nitrogen oxides[e]		1.4[f]		1.0[g]	6.9[g]		
Sulfur oxides[e]	B	0.2	0.2	0.2	0.2		
Carbon dioxide[h]	C				1,475.8	1,835.6	1,924.7
TOC[j]	E	24.3		12.1			
Methane	E	2.4		4.3			
TNMOC	E	21.9		7.8			

[a] Units are in grams of pollutant/kg of dry wood burned.
[b] Pre-Phase I = Not certified to 1988 EPA emission standards; Phase I = Certified to 1988 EPA emission standards; Phase II = Certified to 1990 EPA emission standards; All = Average of emission factors for all devices.
[c] Certified = Certified pursuant to 1988 NSPS; Exempt = Exempt from 1988 NSPS (i.e., air : fuel >35:1).
[d] Exempt = Exempt from 1988 NSPS (i.e., device weight >800 kg).
[e] References 6 - 14, 23 - 27, 29. PM-10 is defined as equivalent to total catch by EPA method 5H train.
[f] Rating = C.
[g] Rating = E.
[h] References 13, 24 - 27, 29.
[j] References 13, 17 - 18. TOC = Total organic compounds; TNMOC = Total nonmethane organic compounds. Data show a high degree of variability within the source population. Factors may not be accurate for individual sources.

the revision of these emission factors is contained in the emission factor documentation.[29] These tables include emission factors for criteria pollutants (PM_{10}, CO, NO_x, SO_x), CO_2, and total organic compounds (TOCs). The emission factors are presented by wood heater type. PM_{10} and CO emission factors are further classified by stove certification category. Phase II stoves are those certified to meet the July 1, 1990, EPA standards; Phase I stoves meet only the July 1, 1988, EPA standards; and Pre-Phase I stoves do not meet any of the EPA standards but in most cases do necessarily meet the Oregon 1986 certification standards.[1] The emission factors for PM and CO in Tables 3.1.5-1 and -2 are averages, derived entirely from field test data obtained under actual operating conditions. Still, there is a potential for higher emissions from some wood stove, pellet stove, and masonry heater models.

As mentioned above, particulate emissions are defined as the total emissions equivalent to that collected by EPA Method 5H. This method employs a heated filter followed by three impingers, an unheated filter, and a final impinger. Particulate emissions factors are presented as values equivalent to that collected with Method 5H. Conversions are employed, as appropriate, for data collected with other methods.

Emission Calculations. The pollutant emissions are estimated to be a fraction of the total mass of wood combusted. Hourly pollutant emissions are calculated using the following equation:

$$E = EF \cdot W \cdot \frac{1\ ton}{2{,}000\ lb}$$

where E = Pollutant hourly emissions (lb of pollutant/hour)
EF = Emission factor (lb of pollutant/ton of dry wood)
W = Amount of wood burned in 1 hour (lb of dry wood/hour)

Example

Hourly emissions of carbon monoxide from a conventional wood stove are estimated using the following assumptions:

EF = 230.8 lb of CO/ton of dry wood
W = 10 lb of dry wood burned in 1 hour

$$E = 230.8\ \frac{lb\ CO}{ton\ wood} \cdot 10\ \frac{lb\ wood}{hour} \cdot \frac{1\ ton}{2{,}000\ lb}$$

$$= 1.15\ \frac{lb}{hour}\ of\ CO$$

Hazardous Air Pollutants and Trace Elements. Table 3.1.5-3 summarizes emission factors of organic compounds, some of which are hazardous air pollutants (HAPs). Tables 3.1.5-4 and -5 summarize emission factors for polycyclic organic materials (POM). POM is an important component of the condensible fraction of wood smoke. POM contains a wide range of compounds, including organic compounds formed through incomplete combustion by the combination of free radical species in the flame zone. This group, which is classified as a HAP under Title III of the 1990 Clean Air Act Amendments, contains the subgroup of hydrocarbons called polycyclic aromatic hydrocarbons (PAHs).

Table 3.1.5-6 summarizes emission factors for trace elements in residential woodstove smoke.

Mitigation Techniques

Table 3.1.5-7 shows net efficiency by device type, determined entirely from field test data. Net or overall efficiency is the product of combustion efficiency multiplied by heat transfer efficiency. Wood heater efficiency is an important parameter used, along with emission factors and percent degradation, when calculating PM_{10} emission reduction credits. Percent degradation is related to the loss in effectiveness of a wood stove control device or catalyst over a period of operation. Control degradation for any stove, including noncatalytic wood stoves, also may occur as a result of deteriorated seals and gaskets, misaligned baffles and bypass mechanisms, broken refractories, or other damaged functional components. The increase in emissions that can result from control degradation has not been quantified. However, recent wood stove testing in Colorado and Oregon should produce results that allow estimation of emissions as a function of stove age.

The use of dry, cured wood should decrease the amount of smoldering consumption that occurs and thereby reduce total emissions. The emission factor for flaming consumption ranges from 20-60 percent that of smoldering consumption, depending on the fuel type and pollutant species (see Table 3.1.2-1).

Splitting wood to less than 8 inches in diameter will increase the surface area-to-volume ratio of the fuel and thereby decrease the amount of smoldering consumption that will occur.

For mitigation techniques involving firewood sales, the reader is encouraged to review Section 3.1.2 of this document.

Table 3.1.5-3
Organic Compound Emission Factors for Residential Wood Combustion[a] (English and Metric Units)
(Source Classification Codes)

(Emission Factor Rating: E)[b]

Compounds	Wood Stove Type			
	Conventional (SCC 2104008051)		Catalytic (SCC 2104008030)	
	(lb/ton)	(g/kg)	(lb/ton)	(g/kg)
Ethane	1.470	0.735	1.376	0.688
Ethylene	4.490	2.245	3.482	1.741
Acetylene	1.124	0.562	0.564	0.282
Propane	0.358	0.179	0.158	0.079
Propene	1.244	0.622	0.734	0.367
i-Butane	0.028	0.014	0.010	0.005
n-Butane	0.056	0.028	0.014	0.007
Butenes[c]	1.192	0.596	0.714	0.357
Pentenes[d]	0.616	0.308	0.150	0.075
Benzene	1.938	0.969	1.464	0.732
Toluene	0.730	0.365	0.520	0.260
Furan	0.342	0.171	0.124	0.062
Methyl Ethyl Ketone	0.290	0.145	0.062	0.031
2-Methyl Furan	0.656	0.328	0.084	0.042
2,5-Dimethyl Furan	0.162	0.081	0.002	0.011
Furfural	0.486	0.243	0.146	0.073
O-Xylene	0.202	0.101	0.186	0.093

[a] Reference 17. Units are in lb of pollutant/ton of dry wood burned and grams of pollutant/kg of dry wood burned.

[b] Data show a high degree of variability within the source population. Factors may not be accurate for individual sources.

[c] 1-butene, i-butene, t-2-butene, c-2-butene, 2-me-1-butene, 2-me-butene are reported as butenes.

[d] 1-pentene, t-2-pentene, and c-2-pentene are reported as pentenes.

Table 3.1.5-4
PAH Emission Factors for Residential Wood Combustion[a]
(English Units)

(Emission Factor Rating: E)[b]

Pollutant	Stove Type			
	Conventional[c] (SCC 2104008051)	Noncatalytic[d] (SCC 2104008050)	Catalytic[e] (SCC 2104008030)	Exempt Pellet[f] (SCC 2104008053)
PAH				
Acenaphthene	0.010	0.010	0.006	
Acenaphthylene	0.212	0.032	0.068	
Anthracene	0.014	0.009	0.008	
Benzo(a)Anthracene	0.020	<0.001	0.024	
Benzo(b)Fluoranthene	0.006	0.004	0.004	2.60E-05
Benzo(g,h,i)Fluoranthene		0.028	0.006	
Benzo(k)Fluoranthene	0.002	<0.001	0.002	
Benzo(g,h,i)Perylene	0.004	0.020	0.002	
Benzo(a)Pyrene	0.004	0.006	0.004	
Benzo(e)Pyrene	0.012	0.002	0.004	
Biphenyl		0.022		
Chrysene	0.012	0.010	0.010	7.52E-05
Dibenzo(a,h)Anthracene	0.000	0.004	0.002	
7,12-Dimethylbenz(a)Anthracene	0.020	0.004 0.008	0.012	5.48E-05
Fluoranthene	0.024	0.014	0.014	
Fluorene	0.000	0.020	0.004	
Indeno(1,2,3,cd)Pyrene		0.004		
9-Methylanthracene		0.002		
12-Methylbenz(a)Anthracene		<0.001		
3-Methylchlolanthrene		0.030		
1-Methylphenanthrene	0.288	0.144	0.186	
Naphthalene		0.000		
Nitronaphthalene		0.002		
Perylene	0.078	0.118	0.489	3.32E-05
Phenanthrene		0.000		
Phenanthrol		<0.001		
Phenol	0.024	0.008	0.010	4.84E-05
Pyrene				
PAH Total	**0.730**	**0.500**	**0.414**	

[a] Units are in lb of pollutant/ton of dry wood burned.
[b] Data show a high degree of variability within the source population and/or came from a small number of sources. Factors may not be accurate for individual sources.
[c] Reference 17.
[d] References 15,18-20.
[e] References 14-18.
[f] Reference 27. Exempt = Exempt from 1988 NSPSs (i.e., air:fuel>35:1).

Table 3.1.5-5
PAH Emission Factors for Residential Wood Combustion[a]
(Metric Units)
(Source Classification Codes)

(Emission Factor Rating: E)[b]

Pollutant	Stove Type			
	Conventional[c] (SCC 2104008051)	Noncatalytic[d] (SCC 2104008050)	Catalytic[e] (SCC 2104008030)	Exempt Pellet[f] (SCC 2104008053)
PAH				
Acenaphthene	0.005	0.005	0.003	
Acenaphthylene	0.106	0.016	0.034	
Anthracene	0.007	0.004	0.004	
Benzo(a)Anthracene	0.010	<0.001	0.012	
Benzo(b)Fluoranthene	0.003	0.002	0.002	1.30E-05
Benzo(g,h,i)Fluoranthene		0.014	0.003	
Benzo(k)Fluoranthene	0.001	<0.001	0.001	
Benzo(g,h,i)Perylene	0.002	0.010	0.001	
Benzo(a)Pyrene	0.002	0.003	0.002	
Benzo(e)Pyrene	0.006	0.001	0.002	
Biphenyl		0.011		
Chrysene	0.006	0.005	0.005	3.76E-05
Dibenzo(a,h)Anthracene	0.000	0.002	0.001	
7,12-Dimethylbenz(a)Anthracene		0.002		
Fluoranthene	0.010	0.004	0.006	2.74E-05
Fluorene	0.012	0.007	0.007	
Indeno(1,2,3,cd)Pyrene	0.000	0.010	0.002	
9-Methylanthracene		0.002		
12-Methylbenz(a)Anthracene		0.001		
3-Methylchlolanthrene		<0.001		
1-Methylphenanthrene		0.015		
Naphthalene	0.144	0.072	0.093	
Nitronaphthalene		0.000		
Perylene		0.001		
Phenanthrene	0.039	0.059	0.024	1.66E-05
Phenanthrol		0.000		
Phenol		<0.001		
Pyrene	0.012	0.004	0.005	2.42E-05
PAH Total	**0.365**	**0.250**	**0.207**	

[a] Units are in grams of pollutant/kg of dry wood burned.
[b] Data show a high degree of variability within the source population and/or came from a small number of sources. Factors may not be accurate for individual sources.
[c] Reference 17.
[d] References 15, 18 - 20.
[e] References 14 - 18.
[f] Reference 27. Exempt = Exempt from 1988 NSPSs (i.e., air : fuel >35:1).

Table 3.1.5-6
Trace Element Emission Factors for Residential Wood Combustion[a]
(English and Metric Units)
(Source Classification Code)

(Emission Factor Rating: E)[b]

Element	Wood Stove Type					
	Conventional (SCC 2104008051)		Noncatalytic (SCC 2104008050)		Catalytic (SCC 2104008030)	
	(lb/ton)	(g/kg)	(lb/ton)	(g/kg)	(lb/ton)	(g/kg)
Cadmium (Cd)	2.2E-05	1.1E-05	2.0E-05	1.0E-05	4.6E-05	2.3E-05
Chromium (Cr)	<1.0E-06	<1.0E-06	<1.0E-06	<1.0E-05	<1.0E-06	<1.0-E06
Manganese (Mn)	1.7E-04	8.7E-05	1.4E-04	7.0E-05	2.2E-04	1.1E-04
Nickel (Ni)	1.4E-05	7.0E-06	2.0E-05	1.0E-05	2.2E-06	1.0E-06

[a] References 14, 17. Units are in lb of pollutant/ton of dry wood burned and grams of pollutant/kg of dry wood burned.

[b] The data used to develop these emission factors showed a high degree of variability within the source population. Factors may not be accurate for individual sources.

Table 3.1.5-7
Summary of Wood Heater Net Efficiencies[a]

Wood Heater Type	Source Classification Code	Net Efficiency (%)	Reference
Wood Stoves			
Conventional	2104008051	54	26
Noncatalytic	2104008050	68	9, 12, 26
Catalytic	2104008030	68	6, 26
Pellet Stoves[b]			
Certified	2104008053	68	11
Exempt		56	27
Masonry Heaters			
All	2104008055	58	28

[a] Net efficiency is a function of both combustion efficiency and heat transfer efficiency. The percentages shown here are based on data collected from in-home testing.

[b] Certified = Certified pursuant to 1988 NSPSs.
Exempt = Exempt from 1988 NSPSs (i.e., air : fuel >35:1).

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3.2.1 Fugitive Dust from Vehicle Traffic on Unpaved Roads

3.2.1 Fugitive Dust from Vehicle Traffic on Unpaved Roads

Source of Emissions Data

The following information was obtained from:

U.S. Environmental Protection Agency. 1995. *Compilation of Air Pollutant Emission Factors, Volume I: Stationary Point and Area Sources* (Fifth Edition–DRAFT). Section 13.2.1.

Estimating Emissions

General Description. Dust plumes trailing behind vehicles traveling on unpaved roads are a familiar sight in rural areas of the United States. When a vehicle travels an unpaved road, the force of the wheels on the road surface causes pulverization of surface material. Particles are lifted and dropped from the rolling wheels, and the road surface is exposed to strong air currents in turbulent shear with the surface. The turbulent wake behind the vehicle continues to act on the road surface after the vehicle has passed.

Emission Factor Data. The quantity of dust emissions from a given segment of unpaved road varies linearly with the volume of traffic. Field investigations also have shown that emissions depend on correction parameters (average vehicle speed, average vehicle weight, average number of wheels per vehicle, road surface texture, and road surface moisture) that characterize the condition of a particular road and the associated vehicle traffic.[1-4]

Dust emissions from unpaved roads have been found to vary in direct proportion to the fraction of silt (particles smaller than 75 micrometers in diameter) in the road surface materials.[1] The silt fraction is determined by measuring the proportion of loose dry surface dust that passes a 200-mesh screen, using the ASTM-C-136 method. Table 3.2.1-1 summarizes measured silt values for industrial and rural unpaved roads.

Since the silt content of a rural dirt road will vary with location, it should be measured for use in projecting emissions. As a conservative approximation, the silt content of the parent soil in the area can be used. Tests, however, show that road silt content is normally lower than in the surrounding parent soil, because the fines are continually removed by the vehicle traffic, leaving a higher percentage of coarse particles.

Unpaved roads have a hard, generally nonporous surface that usually dries quickly after a rainfall. The temporary reduction in emissions caused by precipitation may be accounted for by not considering emissions on "wet" days (more than 0.254 millimeter [0.01 inch] of precipitation).

Table 3.2.1-1
Typical Silt Content Values of Surface Material on Industrial and Rural Unpaved Roads[a]

Industry	Road Use or Surface Material	Plant Sites	No. of Samples	Silt Content (%)	
				Range	Mean
Copper smelting	Plant road	1	3	16 - 19	17
Iron and steel production	Plant road	19	135	0.2 - 19	6.0
Sand and gravel processing	Plant road	1	3	4.1 - 6.0	4.8
Stone quarrying and processing	Plant road	2	10	2.4 - 16	10
	Haul road	1	10	5.0 - 15	9.6
Taconite mining and processing	Service road	1	8	2.4 - 7.1	4.3
	Haul road	1	12	3.9 - 9.7	5.8
Western surface coal mining	Haul road	3	21	2.8 - 18	8.4
	Access road	2	2	4.9 - 5.3	5.1
	Scraper route	3	10	7.2 - 25	17
	Haul road (freshly graded)	2	5	18 - 29	24
Rural roads	Gravel/crushed limestone	3	9	5.0 - 13	8.9
	Dirt	7	32	1.6 - 68	12
Municipal roads	Unspecified	3	26	0.4 - 13	5.7
Municipal solid waste landfills	Disposal routes	4	20	2.2 - 21	6.4

[a]References 1, 5-16.

The following empirical expression may be used to estimate the quantity of size-specific particulate emissions from an unpaved road, per vehicle kilometer traveled (VKT) or vehicle mile traveled (VMT):

$$E = k \cdot (1.7) \cdot \left(\frac{s}{12}\right) \cdot \left(\frac{S}{48}\right) \cdot \left(\frac{W}{2.7}\right)^{0.7} \cdot \left(\frac{w}{4}\right)^{0.5} \cdot \left(\frac{365-p}{365}\right) \quad (kg/VKT)$$

$$E = k \cdot (5.9) \cdot \left(\frac{s}{12}\right) \cdot \left(\frac{S}{30}\right) \cdot \left(\frac{W}{3}\right)^{0.7} \cdot \left(\frac{w}{4}\right)^{0.5} \cdot \left(\frac{365-p}{365}\right) \quad (lb/VMT)$$

where E = emission factor
k = particle size multiplier (dimensionless)
s = silt content of road surface material (%)
S = mean vehicle speed, km/hr (mph)
W = mean vehicle weight, Mg (ton)
w = mean number of wheels
p = number of days with at least 0.254 mm (0.01 inch) of precipitation per year (see discussion below about the effect of precipitation.)

The particle size multiplier in the equation, k, varies with aerodynamic particle size range as follows:

Aerodynamic Particle Size Multiplier for Equation					
≤30 μm[a]	≤30 μm	≤15 μm	≤10 μm	≤5 μm	≤2.5 μm
1.0	0.80	0.50	0.36	0.20	0.095

[a]Stokes diameter.

The number of wet days per year, p, for the geographical area of interest should be determined from local climatic data. Figure 3.2.1-1 gives the geographical distribution of the mean annual number of wet days per year in the United States.[17] The equation is rated "A" for dry conditions (p = 0) and "B" for annual or seasonal conditions (p > 0). The lower rating is applied because extrapolation to seasonal or annual conditions assumes that emissions occur at the estimated rate on days without measurable precipitation and, conversely, are absent on days with measurable precipitation. Clearly, natural mitigation depends not only on how much precipitation falls, but also on other factors affecting the evaporation rate, such as ambient air temperature, wind speed, and humidity. Persons in dry, arid portions of the country may wish to base p (the number of wet days) on a greater amount of precipitation than 0.254 millimeter (0.01 inch). In addition, Reference 18 contains procedures to estimate the emission reduction achieved by the application of water to an unpaved road surface.

The equation retains the assigned quality rating, if applied within the ranges of source conditions that were tested in developing the equation, as follows:

Ranges of Source Conditions for Equation					
Road Silt Content (wt %)	Mean Vehicle Weight		Mean Vehicle Speed		Mean No. of Wheels
	mg	ton	km/hr	mph	
4.3 - 20	2.7 - 142	3 - 157	21 - 64	13 - 40	4 - 13

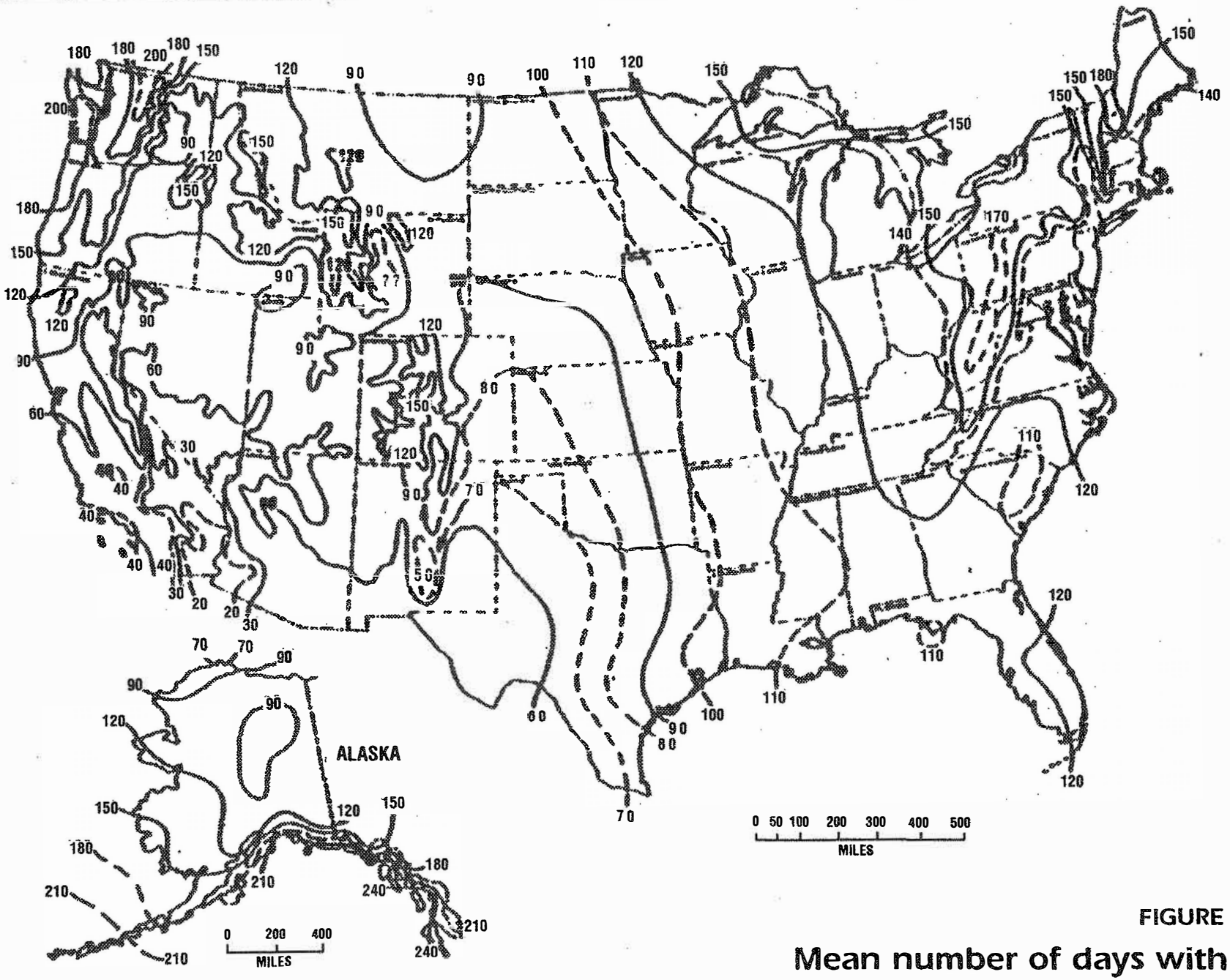

FIGURE 3.2.1-1

Mean number of days with 0.01 inch of precipitation in the U.S.

Moreover, to retain the quality rating of the equation when addressing a specific unpaved road, it is necessary that reliable correction parameter values be determined for the road in question. The field and laboratory procedures for determining road surface silt content are given in Appendix C of *AP-42*. In the event that site-specific values for correction parameters cannot be obtained, the appropriate mean values from Table 3.2.1-1 may be used, but the quality rating of the equation is reduced by one letter.

To calculate annual average emissions, multiply the equation by annual vehicle distance traveled (VDT). Annual average values for each of the correction parameters are to be substituted for the equation. Worst-case emissions, corresponding to dry road conditions, may be calculated by setting p = 0 in the equation (equivalent to dropping the last term from the equation). A separate set of nonclimatic correction parameters and a higher than normal VDT value may also be justified for the worst-case average period (usually 24 hours). Similarly, in using the equation to calculate emissions for a 91-day season of the year, replace the term (365-p)/365 with the term (91-p)/91, and set p equal to the number of wet days in the 91-day period. Use appropriate seasonal values for the nonclimatic correction parameters and for VDT.

Emission Calculations. The equation provided above produces an emission factor that can be used to estimate dust emissions from vehicular traffic traveling on unpaved roads. The following example illustrates how to select the appropriate data to be used in the equation. The result of the calculation, an emission factor, will then be used to estimate hourly emissions for the given scenario.

Example

A stand of trees located in western Colorado is scheduled to be harvested during June, July, and August of next year. One concern about the project is the impact to local air quality from fugitive dust, particularly $PM_{2.5}$, generated by log trucks traveling on rural, unpaved roads. To perform the evaluation, assume the following:

Log trucks are loaded (weighing approximately 100 Mg).
Log trucks have 12 wheels.
The average travel speed of the log trucks is 25 kph.
There are ten round trips per day (distance traveled is 10 kilometers one way).
Logging operations will occur 6 days per week.
Roads have a mean silt content of 12 percent (from Table 3.2.1-1).

Based on this information, the following parameters were selected:

k = 0.095 (dimensionless)
s = 12%

S = 25 km/hr (mph)
W = 100 Mg (ton)
w = 12 mean number of wheels
p = 10 wet days during the logging period (from local climatic data)

$$E = 0.095 \cdot (1.7) \cdot \left(\frac{12}{12}\right) \cdot \left(\frac{25}{48}\right) \cdot \left(\frac{100}{2.7}\right)^{0.7} \cdot \left(\frac{12}{4}\right)^{0.5} \cdot \left(\frac{92-10}{92}\right) \quad (kg/VKT)$$

$$= 1.63 \ kg/VKT \ of \ PM_{2.5}$$

Local Climatic Data

Monthly summaries of climatological data for each state are published by the National Oceanic and Atmospheric Administration (NOAA). These summaries provide daily precipitation data recorded at all weather stations throughout the state.

To determine the number of wet days, p, obtain monthly summaries for the months during the construction period. The climatological summary provides a map describing the names and locations of all weather stations throughout the state. Locate the weather station nearest the construction activities. Referring to the daily precipitation tables for each month of the analysis, find the appropriate station's data. Sum up the number of days during the month that exceed 0.01 inch of precipitation. The total number of wet days during the construction period is "p."

Please note: Given the values of the silt loading, and the number of wet days per year, the quality of the calculated emission factor is rated C. This rating can be improved if site-specific silt contents are available and/or local climatic data demonstrate that there are no wet days during the construction period (p=0).

Daily emissions can be estimated with the following equation:

$$E = \left(EF, \frac{kg}{VKT}\right) \cdot (Distance \ traveled, \ km) \cdot ADT$$

Substituting the values for the emission factor, distance traveled, and average daily traffic (ADT), daily emissions of $PM_{2.5}$ are as follows:

$$E = \left(1.63 \frac{kg}{VKT}\right) \cdot (10\ km) \cdot \left(10 \frac{vehicle\ trips}{day}\right)$$

$$= 163 \frac{kg}{day}\ of\ PM_{2.5}$$

This calculation estimates $PM_{2.5}$ emissions for trucks that are loaded with logs traveling away from the harvest operation site. The calculation for estimating $PM_{2.5}$ emissions generated from truck traffic traveling to the site is an exercise reserved for the user of this manual.

Emissions Model. The Office of Mobile Sources has completed a particulate emission factor model similar to MOBILE5 in the way it operates, called PART5. States can now use PART5 as the official EPA particulate model for PM_{10} inventories and analyses. However, the model will not be required to be used in PM_{10} inventories or analyses until 3 months after the Federal Register announcement, which was scheduled for the fall of 1994.

PART5 is a Fortran program used to analyze the particulate air pollution impact of in-use gasoline-fueled and diesel-fueled motor vehicles. It calculates particle emission factors in grams per mile (g/mi) from on-road automobiles, trucks, and motorcycles, for particle sizes of up to 10 micrometers. The particulate matter emission factors include exhaust particulate, exhaust particulate components, brake wear, tire wear, and reentrained road dust, all of which are required for PM_{10} inventories and analyses. The model is appropriate for comparative analyses, such as comparing the potential impact of one traffic control measure to another.

The program contains default values for most data required for the calculation of all the emission factors, but it also allows for user-supplied data in many cases. The model includes an option to print gaseous SO_2, the calculation of fugitive dust for paved and unpaved roads based on algorithms developed by the Office of Air Quality Planning and Standards (presented in this section and Section 3.2.2, "Vehicle Traffic on Paved Roads") and an option to calculate idle emissions developed from manufacturers' data. The mileage accumulation rates, vehicle counts, diesel sales fractions, registration distributions, and catalyst fractions also were updated to be consistent with MOBILE5.

PART5 will require, at a minimum, the following microcomputer hardware configuration for DOS machines:

- IBM-compatible 80386 or better (such as 80486) capable of using extended/expanded memory
- At least 2 MB of RAM
- Math coprocessor chip (such as Intel 80387)

The user's guide and model code are available from the Office of Mobile Sources bulletin board on EPA's Technology Transfer Network.

Mitigation Techniques[18-21]

Common control techniques for unpaved roads are paving, surface-treating with penetration chemicals, working stabilization chemicals into the roadbed, watering, and traffic control regulations. Chemical stabilizers work either by binding the surface material or by enhancing moisture retention. Paving, as a control technique, often is not economically practical. Surface chemical treatment and watering can be accomplished at moderate to low costs, but frequent treatments are required. Traffic controls, such as speed limits and traffic volume restrictions, provide moderate emission reductions, but may be difficult to enforce.

The control efficiencies achievable by paving can be estimated by comparing emission factors for unpaved and paved road conditions, relative to airborne particle size range of interest. The predictive emission factor equation for paved roads, given in Section 3.2.2, "Vehicle Traffic on Paved Roads," requires estimation of the silt loading on the traveled portion of the paved surface, which in turn depends on whether the pavement is periodically cleaned. Unless curbing is to be installed, the effects of vehicle excursion onto shoulders (berms) also must be taken into account in estimating control efficiency.

The control efficiencies afforded by the periodic use of road stabilization chemicals are much more difficult to estimate. The application parameters that determine control efficiency include dilution ratio, mass of diluted chemical per road area, and application frequency. Other factors that affect the performance of chemical stabilizers include vehicle characteristics (for example, traffic volume and average weight) and road characteristics (for example, bearing strength).

Besides water, petroleum resin products historically have been the dust suppressants most widely used on industrial unpaved roads. Figure 3.2.1-2 presents a method to estimate average control efficiencies associated with petroleum resins applied to unpaved roads.[19] Several items should be noted:

1. The term "ground inventory" represents the total volume (per unit area) of petroleum resin concentrate (*not solution*) applied since the start of the dust control season.

2. Because petroleum resin products must be periodically reapplied to unpaved roads, the use of a time-averaged control efficiency value is appropriate. Figure 3.2.1-2 presents control efficiency values averaged over two common application intervals, 2 weeks and 1 month. Other application intervals will require interpolation.

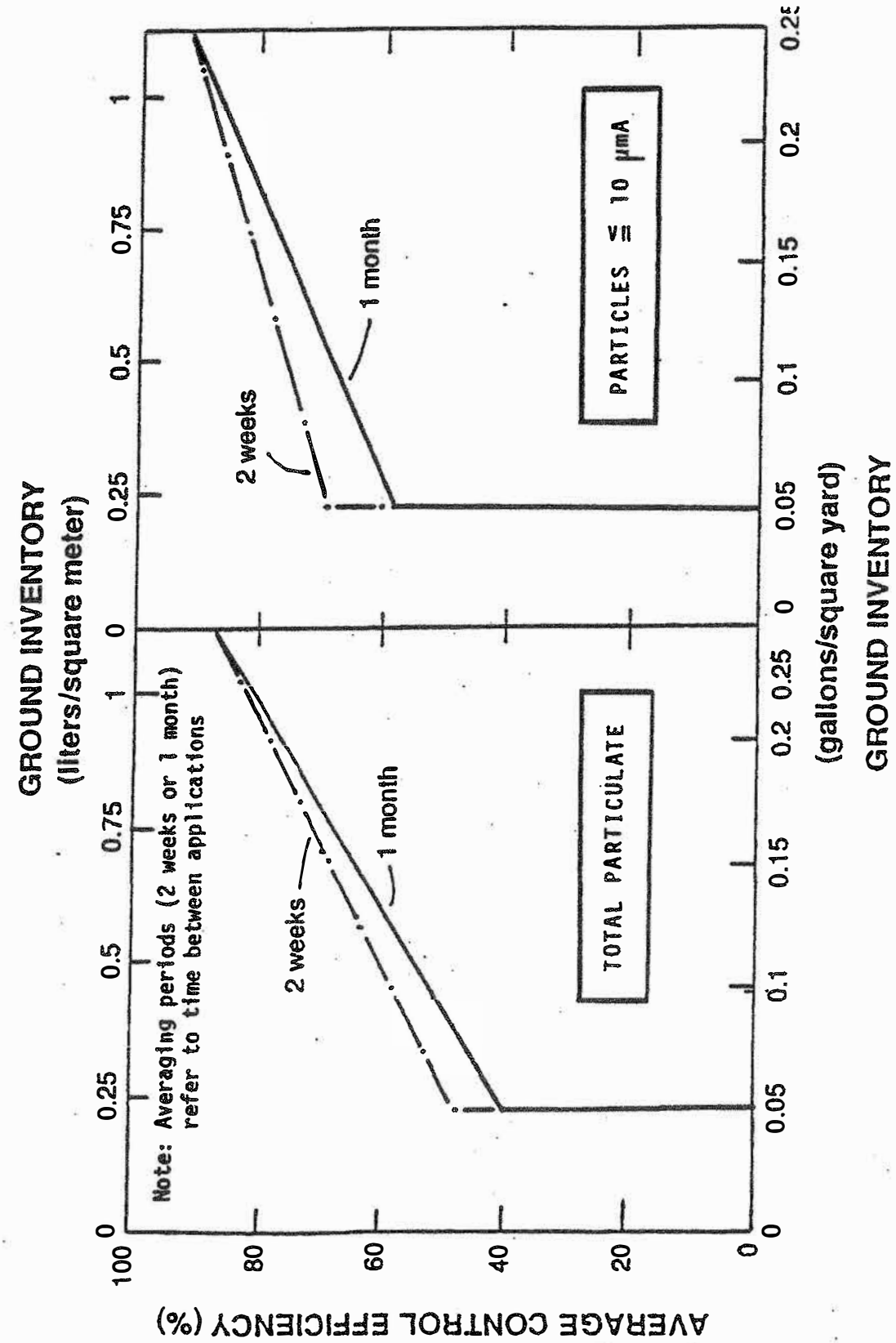

Figure 3.2.1-2. Average control efficiencies over common application intervals.

3. Note that zero efficiency is assigned until the ground inventory reaches 0.2 liter per square meter (0.05 gallon per square yard).

As an example of the application of Figure 3.2.1-2, suppose that the equation was used to estimate an emission factor of 2.0 kilograms per vehicle kilometer traveled for particles equal to or less than 10 microns from a particular road. Also, suppose that, starting on May 1, the road is treated with 1 liter per square meter of a solution (1 part petroleum resin to 5 parts water) on the first of each month through September. Then, the average controlled emission factors shown in Table 3.2.1-2 are found:

Table 3.2.1-2
Example Average Controlled Emission Factors

Period	Ground Inventory (L/m^2)	Average Control Efficiency[a] (%)	Average Controlled Emission Factor (kg/VKT)
May	0.17	0	2.0
June	0.33	62	0.76
July	0.50	68	0.64
August	0.67	74	0.52
September	0.83	80	0.40

[a]From Figure 3.2.1-2, ≤10 μm. Zero efficiency assigned if ground inventory is less than 0.2 L/m^2 (0.05 gal/yd^2).

Newer dust suppressants are successful in controlling emissions from unpaved roads. Specific test results for those chemicals, as well as for petroleum resins and watering, are provided in References 18 through 21.

Control efficiencies from speed reduction can be calculated using the predictive emission factor equation given above.

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1. C. Cowherd, Jr., et al. *Development of Emission Factors for Fugitive Dust Sources,* EPA-450/3-74-037, U.S. Environmental Protection Agency, Research Triangle Park, NC, June 1974.

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9. *Improved Emission Factors for Fugitive Dust from Western Surface Coal Mining Sources*, 2 Volumes, EPA Contract No. 68-03-2924, PEDCo Environmental and Midwest Research Institute, Kansas City, MO, July 1981.

10. T. Cuscino, Jr., et al. *Iron and Steel Plant Open Source Fugitive Emission Control Evaluation*, EPA-600/2-83-110, U.S. Environmental Protection Agency, Cincinnati, OH, October 1983.

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12. C. Cowherd, Jr., and P. Englehart. *Size Specific Particulate Emission Factors for Industrial and Rural Roads*, EPA-600/7-85-038, U.S. Environmental Protection Agency, Cincinnati, OH, September 1985.

13. *PM-10 Emission Inventory of Landfills in the Lake Calumet Area*, EPA Contract 68-02-3891, Work Assignment 30, Midwest Research Institute, Kansas City, MO, September 1987.

14. *Chicago Area Particulate Matter Emission Inventory–Sampling and Analysis*, EPA Contract 68-02-4395, Work Assignment 1, Midwest Research Institute, Kansas City, MO, May 1988.

15. *PM-10 Emissions Inventory Data for the Maricopa and Pima Planning Areas*, EPA Contract 68-02-3888, Engineering-Science, Pasadena, CA, January 1987.

16. *Oregon Fugitive Dust Emission Inventory*, EPA Contract 68-D0-0123, Midwest Research Institute, Kansas City, MO, January 1992.

17. *Climatic Atlas of the United States*, U.S. Department of Commerce, Washington, DC, June 1968.

18. C. Cowherd, Jr., et al. *Control of Open Fugitive Dust Sources*, EPA-450/3-88-008, U.S. Environmental Protection Agency, Research Triangle Park, NC, September 1988.

19. G. E. Muleski, et al. *Extended Evaluation of Unpaved Road Dust Suppressants in the Iron and Steel Industry*, EPA-600/2-84-027, U.S. Environmental Protection Agency, Cincinnati, OH, February 1984.

20. C. Cowherd, Jr., and J. S. Kinsey. *Identification, Assessment and Control of Fugitive Particulate Emissions*, EPA-600/8-86-023, U.S. Environmental Protection Agency, Cincinnati, OH, August 1986.

21. G. E. Muleski and C. Cowherd, Jr. *Evaluation of the Effectiveness of Chemical Dust Suppressants on Unpaved Roads*, EPA-600/2-87-102, U.S. Environmental Protection Agency, Cincinnati, OH, November 1986.

3.2.2 Fugitive Dust from Vehicle Traffic on Paved Roads

3.2.2 Fugitive Dust from Vehicle Traffic on Paved Roads

Source of Emissions Data

The following information was obtained from:

U.S. Environmental Protection Agency. 1995. *Compilation of Air Pollutant Emission Factors, Volume I: Stationary Point and Area Sources* (Fifth Edition–DRAFT). Section 13.2.4.

Estimating Emissions

General Description. Particulate emissions occur whenever vehicles travel over a paved surface, such as a road or parking lot. In general terms, particulate emissions from paved roads originate from the loose material present on the surface. In turn, that surface loading, as it is moved or removed, is continuously replenished by other sources. At industrial sites, surface loading is replenished by spillage of material and trackout from unpaved roads and staging areas. Figure 3.2.2-1 illustrates several transfer processes occurring on public streets.

Various field studies have found that public streets and highways, as well as roadways at industrial facilities, can be major sources of the atmospheric particulate matter within an area.[1-8] Of particular interest in many parts of the United States are the increased levels of emissions from public paved roads when the equilibrium between deposition and removal processes is upset. This situation can occur for various reasons, including application of snow and ice controls, carryout from construction activities in the area, and wind and/or water erosion from surrounding unstabilized areas.

Emission Factor Data. Dust emissions from paved roads have been found to vary with what is termed the "silt loading" present on the road surface as well as the average weight of vehicles traveling the road. The term silt loading (sL) refers to the mass of silt-size material (equal to or less than 75 micrometers in physical diameter) per unit area of the travel surface.[4-5] The total road surface dust loading is that of loose material that can be collected by broom sweeping and vacuuming of the traveled portion of the paved road. The silt fraction is determined by measuring the proportion of the loose dry surface dust that passes through a 200-mesh screen, using the ASTM-C-136 method. Silt loading is the product of the silt fraction and the total loading, and is abbreviated "sL." Additional details on the sampling and analysis of such material are provided in Appendix C of *AP-42*.

The surface sL provides a reasonable means of characterizing seasonal variability in a paved road emission inventory.[9] In many areas of the country, road surface loadings are heaviest during the late winter and early spring months when the residual loading from snow/ice controls is greatest.

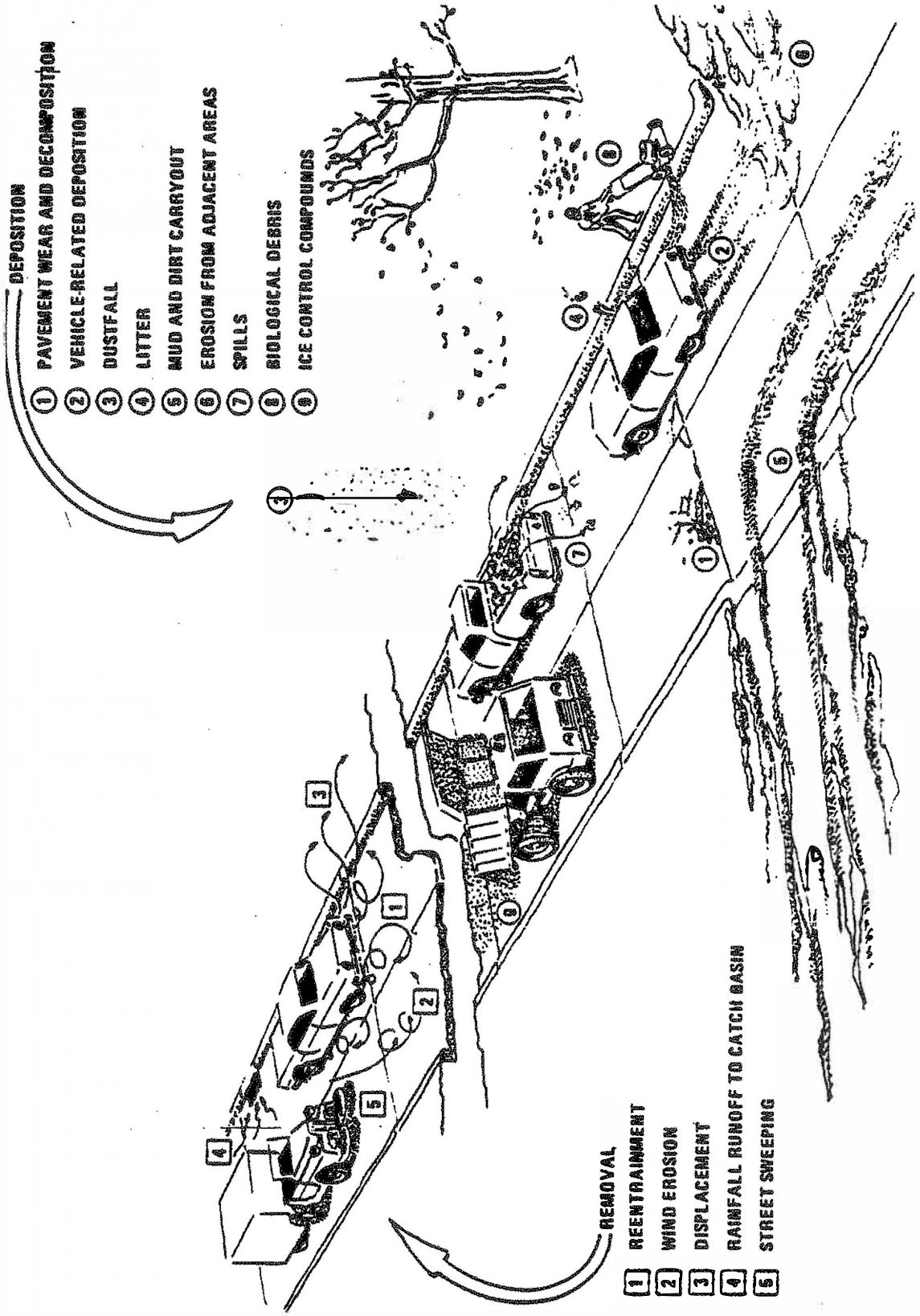

Figure 3.2.2-1. Deposition and removal processes.

The quantity of dust emissions from vehicle traffic on a paved road may be estimated using the following empirical expression[9]:

$$EF = k\ (sL/2)^{0.65}\ (W/3)^{1.5}$$

where EF = particulate emission factor
k = base emission factor for particle size range and units of interest (see below)
sL = road surface silt loading (grams per square meter, or g/m^2)
W = average weight (tons) of the vehicles traveling the road

The particle size multiplier (k) above varies with aerodynamic size range as shown in Table 3.2.2-1.

Table 3.2.2-1
Particle Size Multipliers for Paved Road Equation

Size Range[a]	Multiplier k[b]		
	g/VKT	g/VMT	lb/VMT
$PM_{2.5}$	2.1	3.3	0.0073
PM_{10}	4.6	7.3	0.016
PM_{15}	5.5	9.0	0.020
PM_{30}[c]	24	38	0.082

[a]Refers to airborne particulate matter (PM_x) with an aerodynamic diameter equal to or less than x microns.
[b]Units shown are grams per vehicle kilometer traveled (g/VKT), grams per vehicle mile traveled (g/VMT), and pounds per vehicle mile traveled (lb/VMT).
[c]PM_{30} is sometimes termed "suspendable particulate" (SP) and is often used as a surrogate for TSP.

To determine particulate emissions for a specific particle size range, use the appropriate value of k above.

The above equation is based on a regression analysis of numerous emission tests, including 65 tests for PM_{10}.[9] Sources tested include public paved roads, as well as controlled and uncontrolled industrial paved roads. The equations retain the quality rating of A (B for $PM_{2.5}$) if applied within the range of source conditions that were tested in developing the equation as follows:

Silt loading: 0.02 - 400 g/m^2
0.03 - 570 $grain/ft^2$

Mean vehicle weight:	2.0	-	42 tons
	1.8	-	38 Mg
Mean vehicle speed:	10	-	55 mph
	16	-	88 km/hr

To retain the quality rating for the emission factor equation when it is applied to a specific paved road, it is necessary that reliable correction parameter values for the specific road in question be determined. The field and laboratory procedures for determining surface material silt content and surface dust loading are summarized in Appendix C of *AP-42*. In the event that site-specific values cannot be obtained, an appropriate value for an industrial road may be selected from the mean values given in Table 3.2.2-1, but the quality rating of the equation should be reduced by one level.

With the exception of limited access roadways, which are difficult to sample, the collection and use of site-specific sL data for public paved road emission inventories are strongly recommended. Although hundreds of public paved road sL measurements have been made since 1980,[7, 13-20] uniformity has been lacking in sampling equipment and analysis techniques, in roadway classification schemes, and in the types of data reported.[9] The assembled data set (described below) does not yield any readily identifiable, coherent relationship between sL and road class, average daily traffic (ADT), etc. Further complicating any analysis is the fact that, in many parts of the country, paved road sL varies greatly over the course of the year. For example, repeated sampling of the same roads over a period of three calendar years at four Montana municipalities indicated a noticeable annual cycle. Silt loading declines during the first two calendar quarters and increases during the fourth quarter.

Figures 3.2.2-2 and -3 present the cumulative frequency distribution for the public paved road sL database assembled during the preparation of this section.[9] The database includes samples taken from roads that were treated with sand and other snow/ice controls. Roadways are grouped into high and low ADT sets, with 5,000 vehicles per day being the approximate cutpoint. Figures 3.2.2.-2 and -3, respectively, present the cumulative frequency distributions for high and low ADT roads.

In the absence of site-specific sL data to serve as input to a public paved road inventory, conservatively high emission estimates can be obtained by using the following values taken from the figures. For annual conditions, the median sL values of 0.4 gram per square meter can be used for high-ADT roads (excluding limited access roads that are discussed below) and 2.5 grams per square meter for low-ADT roads. Worst-case loadings can be estimated for high-ADT (excluding limited access roads) and low-ADT roads respectively with the 90th percentile values of 7 and 25 grams per square meter. Figures 3.2.2-4 through -7 present similar cumulative frequency distribution information for high- and low-ADT roads, except that the sets were divided based on whether the sample was collected during the first or second half of the year. Information on the 50th and 90th percentile values is summarized in Table 3.2.2-2.

Table 3.2.2-2
Typical Silt Content and Loading Values for Paved Roads at Industrial Facilities[a]
(Metric and English Units)

Industry	No. of sites	No. of samples	Silt content (%)		No. of travel lanes	Total loading x 10^{-3}			Silt loading (g/m^2)	
			Range	Mean		Range	Mean	Units[b]	Range	Mean
Copper smelting	1	3	15.4-21.7	19.0	2	12.9-19.5 45.8-69.2	15.9 55.4	kg/km lb/mi	188-400	292
Iron and steel production	9	48	1.1-35.7	12.5	2	0.006-4.77 0.020-16.9	0.495 1.75	kg/km lb/mi	0.09-79	9.7
Asphalt batching	1	3	2.6-4.6	3.3	1	12.1-18.0 43.0-64.0	14.9 52.8	kg/km lb/mi	76-193	120
Concrete batching	1	3	5.2-6.0	5.5	2	1.4-1.8 5.0-6.4	1.7 5.9	kg/km lb/mi	11-12	12
Sand and gravel processing	1	3	6.4-7.9	7.1	1	2.8-5.5 9.9-19.4	3.8 13.3	kg/km lb/mi	53-95	70
Municipal solid waste landfill	2	7	–	–	2	–	–	–	1.1-32.0	7.4
Quarry	1	6	–	–	2	–	–	–	2.4-14	8.2

[a]References 1-2, 5-6, and 10-12. Values represent samples collected from *industrial* roads. Public road silt loading values are presented in Figures 3.2.2-2 through -7 and Tables 3.2.2-2 and -3.
[b]Multiply entries by 1,000 to obtain stated units.

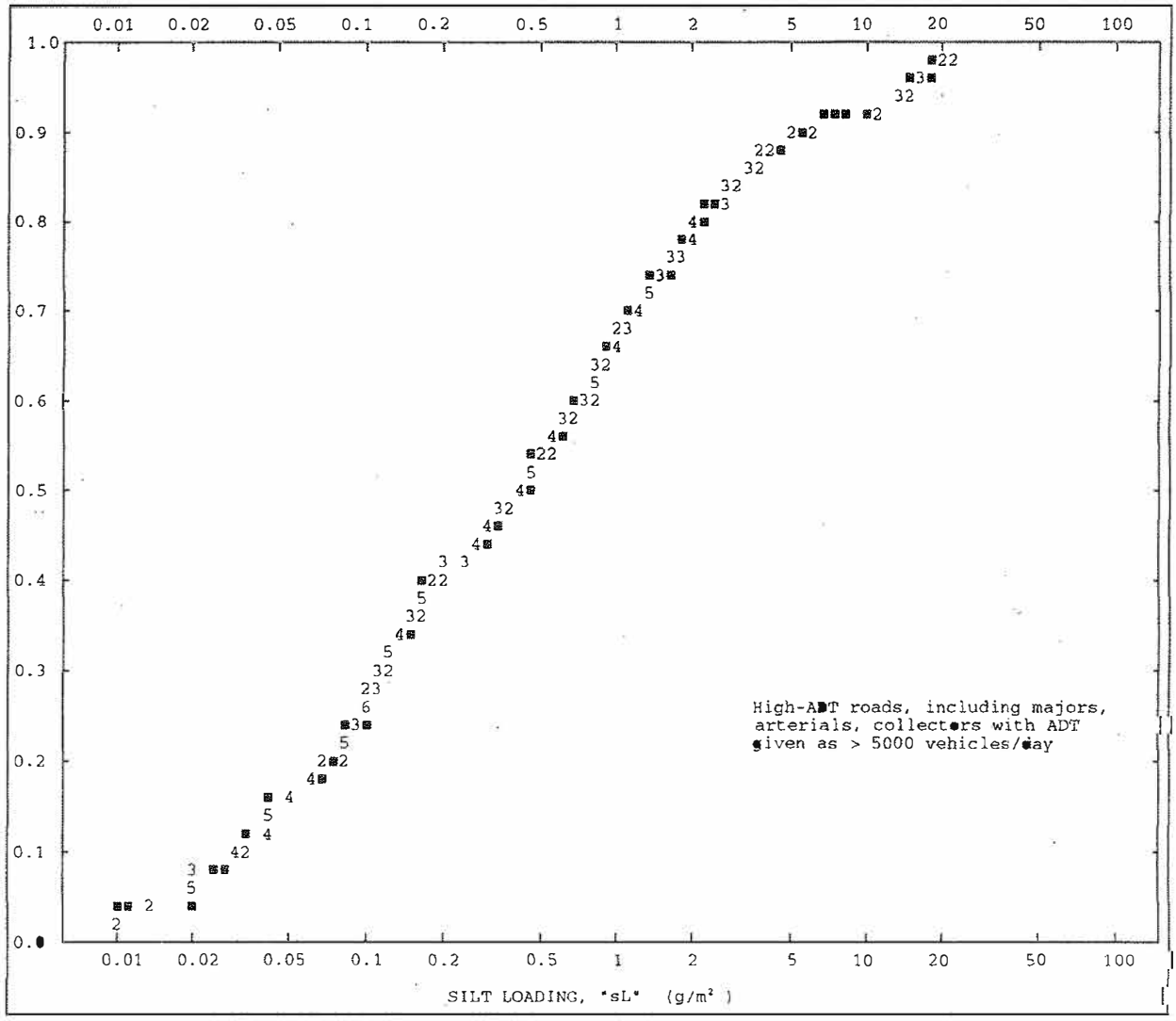

Figure 3.2.2-2. Cumulative frequency distribution for surface silt loading on high-ADT roadways, annual average.

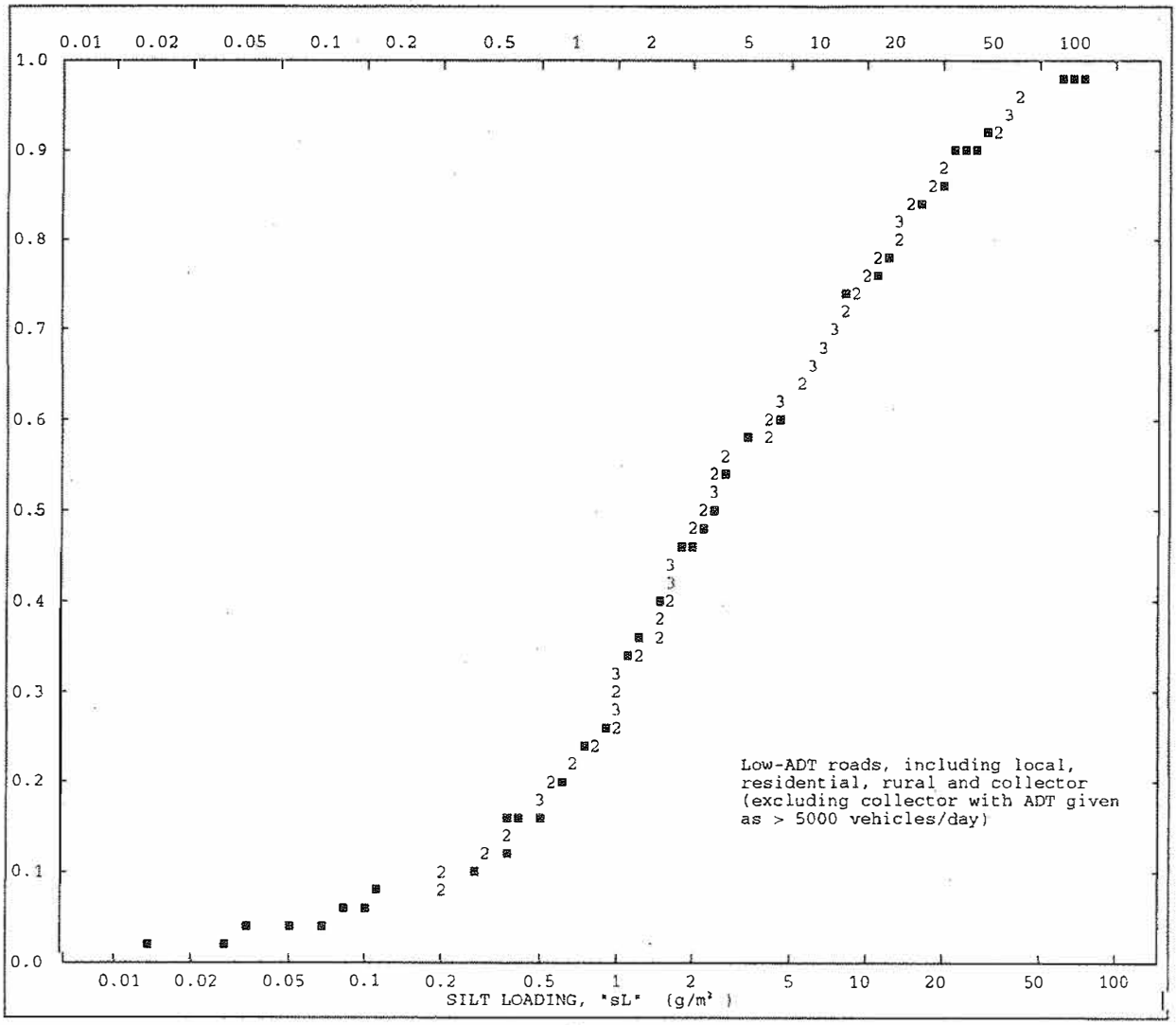

Figure 3.2.2-3. Cumulative frequency distribution for surface silt loading on low-ADT roadways, annual average.

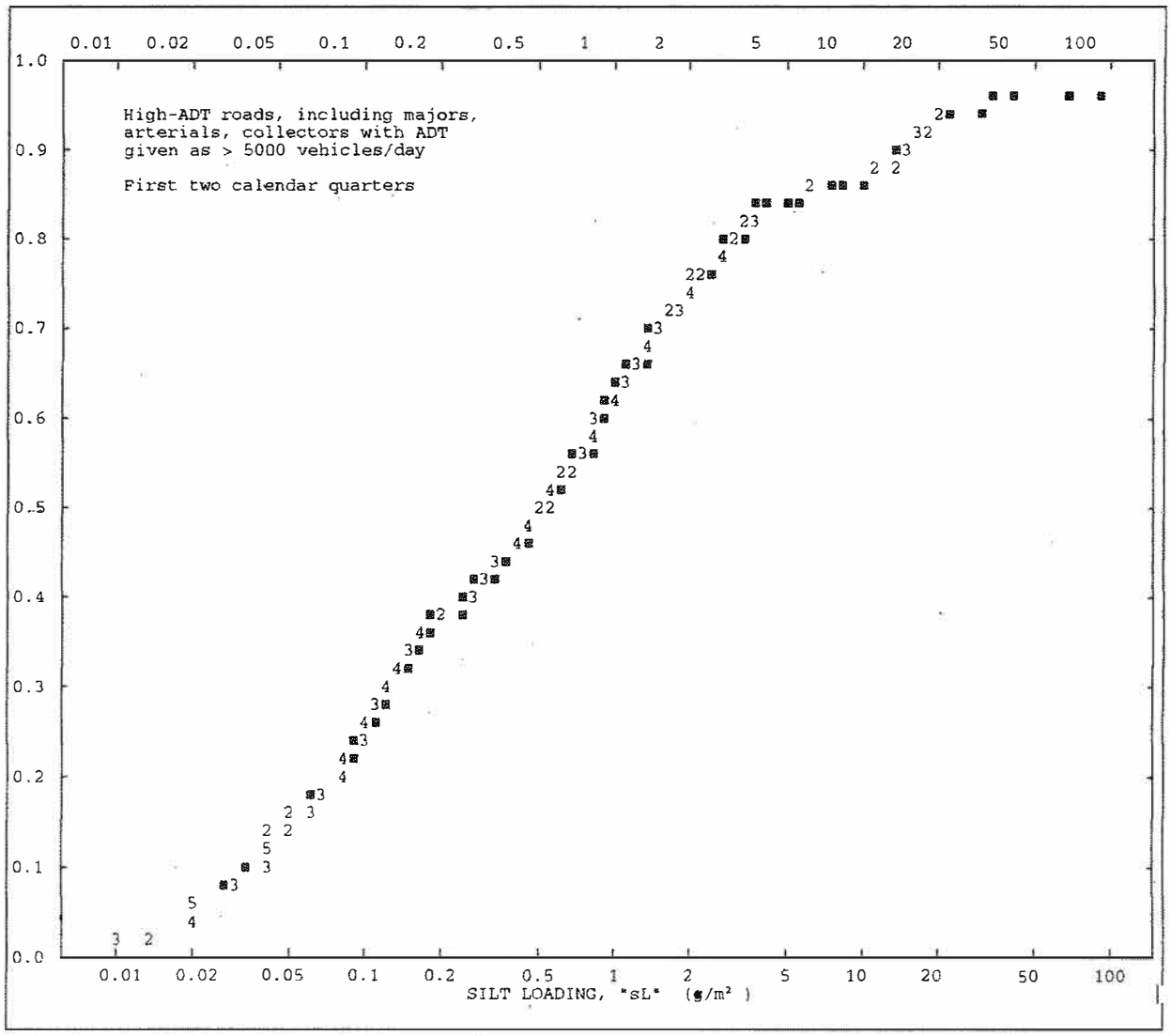
High-ADT roads, including majors,
arterials, collectors with ADT
given as > 5000 vehicles/day
First two calendar quarters
0.01 0.02 0.05 0.1 0.2 0.5 1 2 5 10 20 50 100
1.0 0.9 0.8 0.7 0.6 0.5 0.4 0.3 0.2 0.1 0.0
SILT LOADING, "sL" (g/m²)

Figure 3.2.2-4. Cumulative frequency distribution for surface silt loading on high-ADT roadways, based on samples during first half of the calendar year.

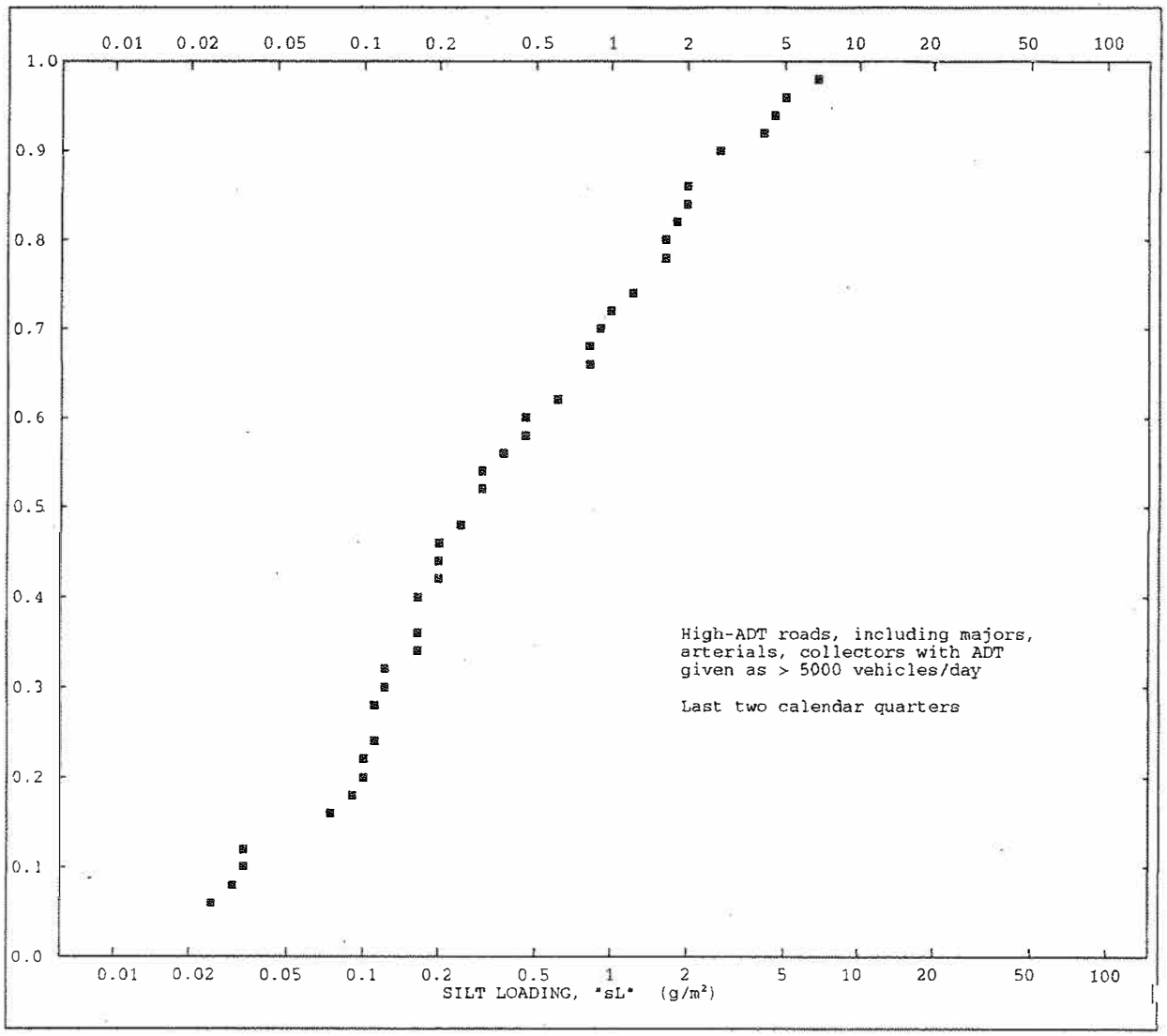

Figure 3.2.2-5. Cumulative frequency distribution for surface silt loading on high-ADT roadways, based on samples during second half of the calendar year.

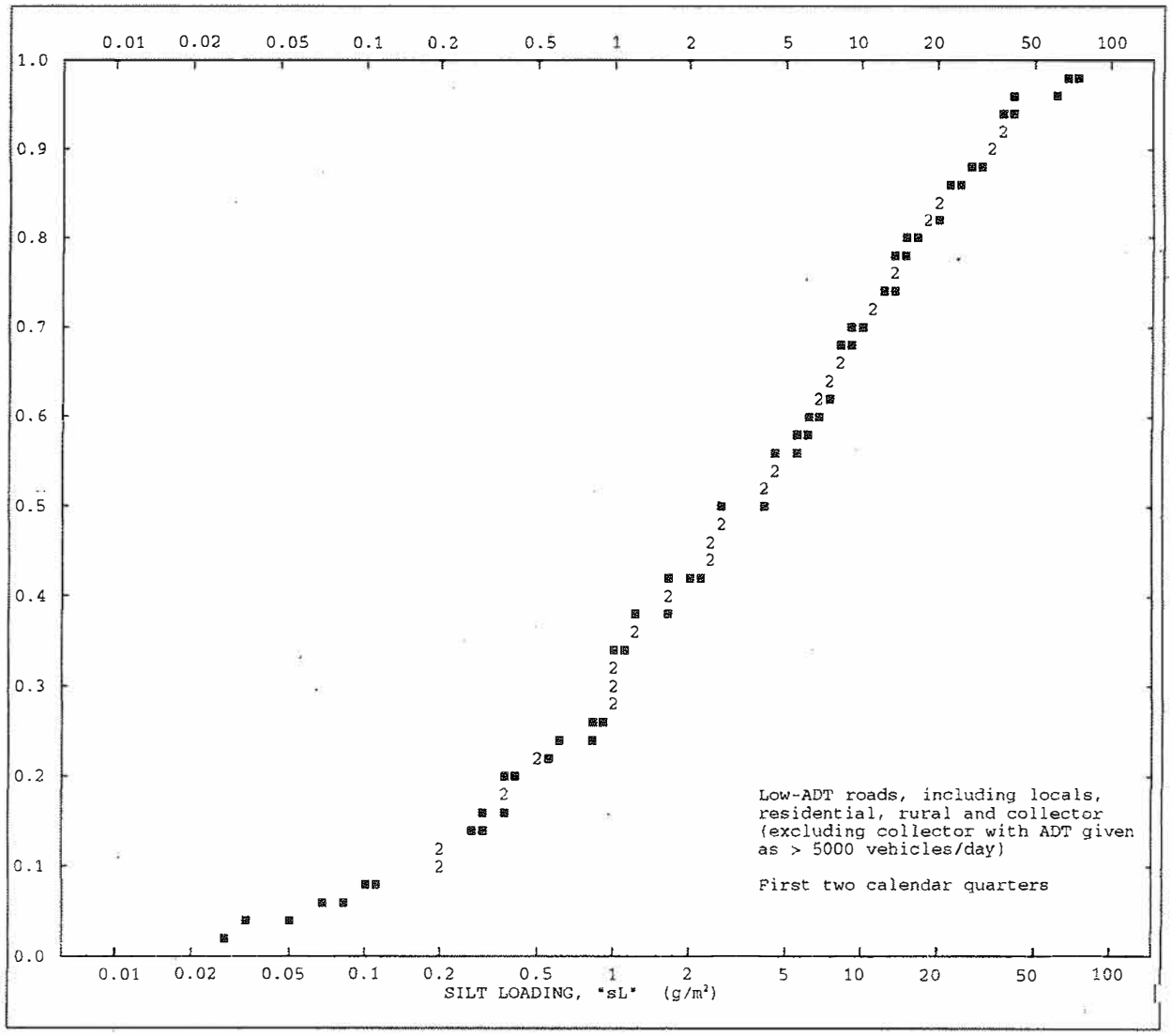

Figure 3.2.2-6. Cumulative frequency distribution for surface silt loading on low-ADT roadways, based on samples during first half of the calendar year.

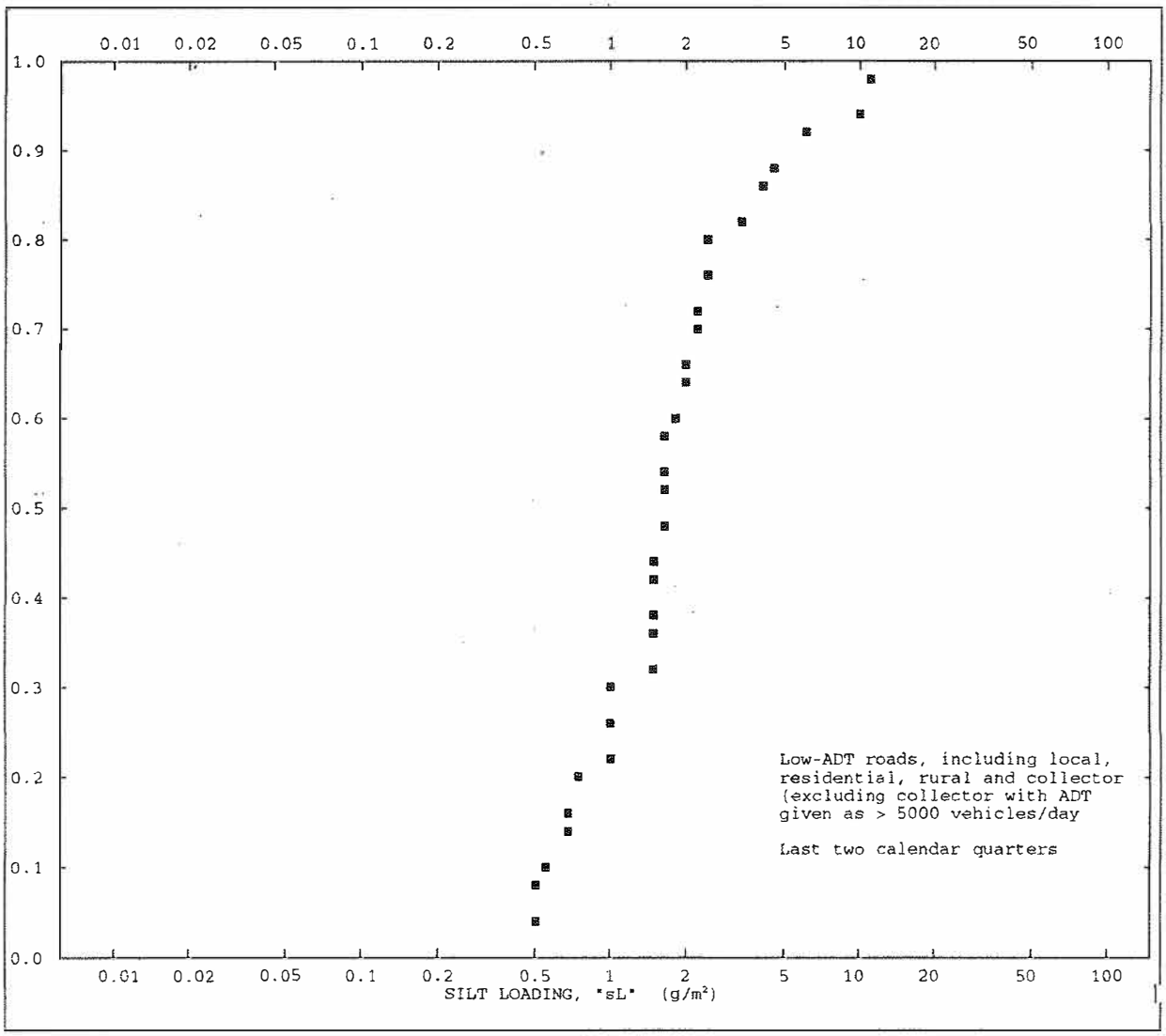

Figure 3.2.2-7. Cumulative frequency distribution for surface silt loading on low-ADT roadways, based on samples during second half of the calendar year.

In the event that sL values are taken from any of the cumulative frequency distribution figures, the quality ratings for the emission estimates should be downgraded two levels.

As an alternative method of selecting sL values in the absence of site-specific data, users can review the public (that is, nonindustrial) paved road sL database presented in Table 3.2.2-3 and can select values that are appropriate for the roads and seasons of interest. Table 3.2.2-4 presents paved road surface loading values together with the city, state, road name, collection date (samples collected from the same road during the same month are averaged), road ADT if reported, classification of the roadway, etc. Recommendation of this approach recognizes that end users of *AP-42* are capable of identifying roads in the database that are similar to roads in the area being inventoried. In the event that sL values are developed in this way, and that the selection process is fully described, then the quality ratings for the emission estimates should be downgraded only one level.

Table 3.2.2-3
Percentiles for Nonindustrial Silt Loading (g/m^2) Database

	High ADT		Low ADT	
Averaging period	**50th**	**90th**	**50th**	**90th**
Annual	0.4	7	2.5	25
January-June	0.5	14	3	30
July-December	0.3	3	1.5	5

Limited access roadways pose severe logistical difficulties in terms of surface sampling, and few sL data are available. Nevertheless, the available data do not suggest great variation in sL for limited access roadways from one part of the country to another. For annual conditions, a default value of 0.02 gram per square meter is recommended for limited access roadways. Even fewer of the available data correspond to worst-case situations, and elevated loadings are observed to be quickly depleted because of high ADT rates. A default value of 0.1 gram per square meter is recommended for short periods of time following application of snow/ice controls to limited access roads.

Emission Calculations. The equation provided above produces an emission factor that can be used to estimate dust emissions from vehicular traffic traveling on paved roads. The following example illustrates how to select the appropriate data to be used in the equation. The result of the calculation, an emission factor, will then be used to estimate hourly emissions for the given scenario.

Example

An alpine community similar to Thompson Falls, Montana, is concerned about the PM_{10} generated by motor vehicles en route to a local ski resort during the month of December. Approximately 5,500 vehicles per day travel through the town at this time of year. The average weight of the vehicles is 2.5 Mg and the average speed is 25 km/hr. Based on this information, the following parameters were selected:

k = 4.6 g/VKT
sL = 1.5 g/m^2 (from Table 3.2.2-3)
W = 2.5 Mg = 2.76 tons

$$EF = \left(4.6 \frac{g}{VKT}\right) \cdot \left(\frac{1.5\ g/m^2}{2}\right)^{0.65} \cdot \left(\frac{2.76\ tons}{3}\right)^{1.5}$$

$$= 3.4 \frac{g}{VKT}$$

Please note: Given the values of the particle size range, particle size multiplier (k), silt loading, mean vehicle weight and speed, the quality of the calculated emission factor is rated B.

Assuming the community is concerned only about the emissions within the town limits (about 2 miles of paved roadway), daily emissions can be estimated with the following equation:

$$E = \left(EF, \frac{g}{VKT}\right) \cdot (Distance\ traveled,\ km) \cdot ADT$$

Substituting the values for the emission factor, distance traveled, and ADT, daily emissions of PM_{10} are as follows:

$$E = \left(3.4 \frac{g}{VKT}\right) \cdot (3.2\ km) \cdot \left(5500 \frac{vehicles}{day}\right)$$

$$= 59{,}500 \frac{g}{day} = 59.5 \frac{kg}{day} \text{ of } PM_{10}$$

Emissions Model. OMS has completed a particulate emission factor model similar to MOBILE5 in the way it operates, called PART5. States can now use PART5 as the official EPA particulate model for PM_{10} inventories and analyses. However, the model will not be required to be used in PM_{10} inventories or analyses until 3 months after the Federal Register announcement, which was scheduled for the fall of 1994.

PART5 is a Fortran program used to analyze the particulate air pollution impact of in-use gasoline-fueled and diesel-fueled motor vehicles. It calculates particle emission factors in grams per mile from on-road automobiles, trucks, and motorcycles, for particle sizes of up to 10 micrometers. The particulate matter emission factors include exhaust particulate, exhaust particulate components, brake wear, tire wear, and reentrained road dust, all of which are required for PM_{10} inventories and analyses. The model is appropriate for comparative analyses, such as comparing the potential impact of one traffic control measure to another.

The program contains default values for most data required for the calculation of all the emission factors, but also allows for user-supplied data in many cases. The model includes an option to print gaseous SO_2, the calculation of fugitive dust for paved and unpaved roads based on algorithms developed by the Office of Air Quality Planning and Standards (presented in this section and Section 3.2.1, "Vehicle Traffic on Unpaved Roads") and an option to calculate idle emissions developed from manufacturers' data. The mileage accumulation rates, vehicle counts, diesel sales fractions, registration distributions, and catalyst fractions also were updated to be consistent with MOBILE5.

PART5 will require, at a minimum, the following microcomputer hardware configuration for DOS machines:

- IBM-compatible 80386 or better (such as 80486) capable of using extended/expanded memory
- At least 2 MB of RAM
- Math coprocessor chip (such as Intel 80387)

The user's guide and model code are available from the OMS bulletin board.

Mitigation Techniques[6,21]

Because of the importance of the surface loading, control techniques for paved roads attempt either to prevent material from being deposited onto the surface (preventive controls) or to remove from the travel lanes any material that has been deposited (mitigative controls). Regulations requiring the covering of loads in trucks, or the paving of access areas to unpaved lots or construction sites, are preventive measures. Examples of mitigative controls include vacuum sweeping, water flushing, and broom sweeping and flushing.

In general, preventive controls are more cost-effective than mitigative controls. The cost-effectiveness of mitigative controls falls off dramatically as the size of an area to be treated increases. That is to say, the number and length of public roads within most areas of interest preclude any widespread and routine use of mitigative controls. On the other hand, because of the more limited scope of roads at an industrial site, mitigative measures may be used quite successfully (especially in situations where truck spillage occurs). Note, however, that public agencies could make effective use of mitigative controls to remove sand/salt from roads after the winter ends.

Because available controls will affect the sL, controlled emission factors may be obtained by substituting controlled loading values into the equation. (Emission factors from controlled industrial roads were used in the development of the equation.) The collection of surface loading samples from treated, as well as baseline (untreated), roads provides a means to track effectiveness of the controls over time.

Table 3.2.2-4
Nonindustrial Paved Road Sampling Data[a]

ST	City	Sampling Location, Street, Road Name	Class[a]	Date	ADT[a]	Silt Loading (g/m^2)	Silt Content (%)	Total Loading (g/m^2)	Comments
MT	Billings	-----[b]	Rural	04/78	50	0.6	18.5	3.4	
MT	Billings	Yellowstone	Residential	04/78	115	0.5	14.3	3.5	
MT	Missoula	Bancroft	Residential	04/78	4000	8.4	33.9	24.9	
MT	Butte	1st St	Residential	04/78	679	24.6	10.6	232.4	
MT	Butte	N Park Pl	Residential	04/78	60	103.7	7	1480.8	
MT	Billings	Grand Ave	Collector	04/78	6453	1.6	19.1	13.05	2 samples, range: 1.0 - 2.2
MT	Billings	4th Ave E	Collector	04/78	3328	7.7	7.7	99.5	
MT	Missoula	6th St	Collector	04/78	3655	26	62.9	6	
MT	Butte	Harrison	Arterial	04/78	22849	1.9	5	37.3	
MT	Missoula	Highway 93	Arterial	04/78	18870	1.9	55.9	3.3	
MT	Butte	Montana	Arterial	04/78	13529	0.8	6.6	11.9	
MT	East Helena	Thurman	Residential	04/83	140	13.1	4.3	305.2	
MT	East Helena	1st St	Local	04/83	780	4	13.6	29	
MT	East Helena	Montana	Collector	04/83	2700	8.2	9.4	86.6	
MT	East Helena	Main St	Collector	04/83	1360	4.7	8.4	55.3	
MT	Libby	6th	Local	03/88	1310	-----	14.8	-----	
MT	Libby	5th	Local	03/88	331	-----	16.5	-----	
MT	Libby	Champion Int So gate	Collector	03/88	800	-----	27.5	-----	
MT	Libby	Mineral Ave	Collector	03/88	5900	7	16	43.5	
MT	Libby	Main Ave btwn 6th &	Collector	03/88	536	61	20.4	299.2	
MT	Libby	California	Collector	03/88	4500	-----	12.1	-----	
MT	Libby	US 2	Arterial	03/88	10850	-----	12.3	-----	
MT	Butte	Garfield Ave	Residential	04/88	562	2.1	10.9	19.3	

Table 3.2.2-4
Nonindustrial Paved Road Sampling Data[a]

ST	City	Sampling Location, Street, Road Name	Class[a]	Date	ADT[a]	Silt Loading (g/m^2)	Silt Content (%)	Total Loading (g/m^2)	Comments
MT	Butte	Continental Dr	Arterial	04/88	5272	0.9	10.1	8.8	
MT	Butte	Garfield Ave	Residential	06/89	562	1	8.7	11.2	
MT	Butte	So Park Ave	Residential	06/89	60	2.8	10.9	25.5	
MT	Butte	Continental Dr	Arterial	06/89	5272	7.2	3.6	197.6	
MT	East Helena	Morton St	Local	08/89	250	1.7	6.8	24.6	
MT	East Helena	Main St	Collector	08/89	2316	0.7	4.1	17	
MT	East Helena	US 12	Arterial	08/89	7900	2.1	12.5	16.5	
MT	Columbia Falls	7th St	Residential	03/90	390	-----	9.5	-----	
MT	Columbia Falls	4th St	Residential	03/90	400	18.8	14.3	131.5	
MT	Columbia Falls	3rd Ave	Residential	03/90	50	-----	14.3	-----	
MT	Columbia Falls	4th Ave	Residential	03/90	1720	-----	5.4	-----	
MT	Columbia Falls	CF Forest	Local	03/90	240	-----	16.3	-----	
MT	Columbia Falls	12th Ave	Collector	03/90	1510	-----	8.8	-----	
MT	Columbia Falls	3rd St	Collector	03/90	1945	-----	7	-----	
MT	Columbia Falls	Nucleus	Collector	03/90	4730	15.4	10	153.9	
MT	Columbia Falls	Plum Creek	Collector	03/90	316	-----	6.2	-----	
MT	Columbia Falls	6th Ave	Collector	03/90	1764	-----	4.2	-----	
MT	Columbia Falls	US 2	Arterial	03/90	13110	2.7	18.7	14.6	
MT	East Helena	Morton	Residential	07/90	250	1.6	17	9.3	
MT	East Helena	Main St	Collector	07/90	2316	5.6	10.6	52.5	
MT	East Helena	US 12	Arterial	07/90	7900	3.2	15.4	20.9	
MT	Columbia Falls	4th Ave	Local	08/90	400	1.5	4	37.7	

Table 3.2.2-4
Nonindustrial Paved Road Sampling Data[a]

ST	City	Sampling Location, Street, Road Name	Class[a]	Date	ADT[a]	Silt Loading (g/m^2)	Silt Content (%)	Total Loading (g/m^2)	Comments
MT	Libby	Main Ave 4th &	Collector	08/90	530	2.4	17.9	13.2	
MT	Columbia Falls	Nucleus	Collector	08/90	5730	0.8	5.3	16	
MT	Columbia Falls	US 2	Arterial	08/90	13039	0.2	7	2.9	
MT	East Helena	Morton	Local	10/90	250	3.4	10.2	33.6	
MT	East Helena	Main	Collector	10/90	2316	4.5	5.6	81.3	
MT	East Helena	US 12	Arterial	10/90	7900	0.6	13.9	4.3	
MT	Columbia Falls	Nucleus	Collector	11/06/90	5670	5.2	13.5	38	
MT	Columbia Falls	US 2	Arterial	11/06/90	15890	1.7	24.1	7.2	
MT	Libby	US 2	Arterial	12/08/90	10000	21.5	9.6	223.9	
MT	Libby	Main Ave 4th &	Collector	12/09/90	530	13.6	27.1	50.3	
MT	Butte	Texas	Collector	12/13/90	3070	1	15.4	6.4	
MT	East Helena	King	Local	01/91	75	1	3.4	30.6	
MT	East Helena	Prickly Pear	Local	01/91	425	12	1.8	666.5	
MT	East Helena	Morton	Local	01/91	250	14.1	3.5	402.3	
MT	East Helena	Main St	Collector	01/91	2316	36.7	12.1	303.4	
MT	East Helena	US 12	Arterial	01/91	7900	0.8	14	5.6	
MT	Thompson Falls	Preston	Local	01/23/91	920	9.2	9.9	93	
MT	Thompson Falls	Highway 200	Collector	01/23/91	5000	33.3	27.2	122.2	
MT	East Helena	Seaver Park Rd	Local	02/91	150	21.6	7.1	304.7	
MT	East Helena	New Lake Helena Dr	Collector	02/91	2140	19.2	9	213.4	
MT	East Helena	Porter	Collector	02/91	850	74.4	7.7	966.8	
MT	Libby	Main Ave 4th &	Collector	02/14/91	530	33.3	18.7	178.2	

Table 3.2.2-4
Nonindustrial Paved Road Sampling Data[a]

ST	City	Sampling Location, Street, Road Name	Class[a]	Date	ADT[a]	Silt Loading (g/m^2)	Silt Content (%)	Total Loading (g/m^2)	Comments
MT	Libby	US 2	Arterial	02/17/91	10000	69.3	21	330.3	
MT	Butte	Texas	Collector	02/21/91	3070	1.2	11	10.9	
MT	Butte	Harrison	Arterial	02/21/91	22849	2.9	7.9	36.6	
MT	Kalispell	3rd btwn Main & 1st	Collector	02/24/91	2653	30.5	24.8	122.9	
MT	Kalispell	Main	Arterial	02/24/91	14730	17.4	20.4	85.2	
MT	Thompson Falls	Preston	Local	02/25/91	920	35.7	17.9	199.6	
MT	Thompson Falls	Highway 200	Collector	02/25/91	5000	66.8	17.8	375.3	
MT	Helena	Montana	Arterial	03/91	21900	15.4	6.2	248.3	
MT	Kalispell	3rd btwn Main & 1st	Collector	03/09/91	2653	39.1	29.1	134.5	
MT	Columbia Falls	Nucleus	Collector	03/91	5670	30.1	17	174.6	2 samples, range: 0.8 - 0.8
MT	Kalispell	Main	Arterial	03/09/91	14730	17.6	24.7	71.4	
MT	Thompson Falls	Preston	Local	03/91	920	4.4	8.3	51	2 samples, range: 2.8 - 5.9
MT	Thompson Falls	Highway 200	Collector	03/91	5000	4.3	15.5	28.9	2 samples, range: 1.0 - 7.5
MT	Libby	Main Ave 4th &	Collector	03/91	530	14.8	33.1	44.9	2 samples, range: 13.5 - 16.1
MT	Libby	US 2	Arterial	03/91	11963	20	19.5	111.9	3 samples, range: 11.4 - 32.4
MT	East Helena	Morton	Local	04/91	250	4.3	8.8	48.7	
MT	East Helena	US 12	Arterial	04/91	7900	0.5	8.7	5.7	
MT	Thompson Falls	Preston	Local	04/91	920	1.2	15.7	6.3	4 samples, range: 0.3 - 4.0
MT	Thompson Falls	Highway 200	Collector	04/04/91	5000	2	13.4	14.7	2 samples, range: 1.1 - 2.2
MT	Libby	Main Ave 4th &	Collector	04/91	530	3.5	44	7.8	2 samples, range: 2.5 - 4.4
MT	Libby	US 2	Arterial	04/91	12945	11.8	20.5	57.2	4 samples, range: 1.2 - 22.9
MT	Kalispell	3rd btwn Main & 1st	Collector	04/14/91	2653	15.1	37.1	40.9	

Table 3.2.2-4
Nonindustrial Paved Road Sampling Data[a]

ST	City	Sampling Location, Street, Road Name	Class[a]	Date	ADT[a]	Silt Loading (g/m^2)	Silt Content (%)	Total Loading (g/m^2)	Comments
MT	Columbia Falls	Nucleus	Collector	04/91	5670	9	19.8	47.6	
MT	Kalispell	Main	Arterial	04/14/91	14730	13	44.5	29.4	
MT	Columbia Falls	Nucleus	Collector	05/91	5670	2.4	17.5	15.9	4 samples, range: 1.3 - 3.8
MT	Columbia Falls	US 2	Arterial	05/91	14712	5.5	20.7	24.8	5 samples, range: 1.5 - 14.2
MT	Libby	Main Ave 4th &	Collector	05/19/91	530	1.7	31	5.7	
MT	Libby	Main Ave 4th &	Collector	06/27/91	530	1.7	24.3	7.1	
MT	Libby	US 2	Arterial	06/27/91	10000	3.8	12.6	30.6	
MT	East Helena	Morton	Local	07/91	250	1.7	11.4	15.3	
MT	East Helena	Main	Collector	07/91	2316	8.8	11	79.7	
MT	Thompson Falls	Preston	Local	07/09/91	920	10.9	11	98.7	
MT	Thompson Falls	Highway 200	Collector	07/09/91	5000	2.1	8.1	25.9	
MT	Helena	Montana	Arterial	07/17/91	21900	0.9	4.7	19.4	
MT	Butte	Texas	Collector	07/26/91	3070	2.5	28.2	8.9	
MT	Butte	Harrison	Arterial	07/26/91	22849	1.6	28.2	5.8	
MT	Kalispell	3rd btwn Main & 1st	Collector	08/03/91	2653	5.8	23	25.3	
MT	Kalispell	Main	Arterial	08/03/91	14730	4	21	19.3	
MT	Columbia Falls	US 2	Arterial	08/11/91	15890	0.1	5.6	2.3	
MT	Missoula	Russel btwn 4th & 5th	Road	08/30/91	5270	1.6	8.3	19.3	
MT	East Helena	US 12	Arterial	08/30/91	7900	7	20.5	34.3	
MT	Butte	Texas	Collector	10/03/91	3070	1	17.7	5.4	
MT	Butte	Harrison	Arterial	10/03/91	22849	2.1	23.1	9.1	
MT	Kalispell	3rd btwn Main & 1st	Collector	10/06/91	2653	10	31.3	31.9	

Table 3.2.2-4
Nonindustrial Paved Road Sampling Data[a]

ST	City	Sampling Location, Street, Road Name	Class[a]	Date	ADT[a]	Silt Loading (g/m^2)	Silt Content (%)	Total Loading (g/m^2)	Comments
MT	Kalispell	Main	Arterial	10/06/91	14730	4.3	27.7	15.7	
MT	East Helena	Morton	Local	10/16/91	250	1.8	31	5.9	
MT	East Helena	Main St	Collector	10/16/91	2316	1.6	20.5	7.7	
MT	East Helena	US 12	Arterial	10/16/91	7900	1	6.7	14.9	
MT	Columbia Falls	Nucleus	Collector	10/20/91	5670	1.9	13.9	13.3	
MT	Columbia Falls	US 2	Arterial	10/20/91	15890	1.2	11.3	10.2	
MT	Kalispell	3rd btwn Main & 1st	Collector	11/06/91	2653	2.2	12.3	17.8	
MT	Kalispell	Main	Arterial	11/28/91	14730	2.7	8.6	30.8	
MT	Thompson Falls	Preston	Local	12/17/91	920	4	18.1	22.5	
MT	Thompson Falls	Highway 200	Collector	12/17/91	5000	1.5	13.2	11.6	
MT	Butte	Texas	Collector	02/02/92	3070	19.1	11.6	164.5	
MT	Butte	Harrison	Arterial	02/02/92	22849	8.3	12	69.3	
MT	East Helena	Morton	Local	02/03/92	250	78.3	9.5	824.7	
MT	Libby	W 4th St	Local	02/03/92	350	36.3	56.3	64.5	
MT	Libby	Main Ave 4th &	Collector	02/03/92	530	10.7	49.9	21.4	
MT	East Helena	Main St	Collector	02/03/92	2316	57.9	14.8	391	
MT	Columbia Falls	Nucleus	Collector	02/03/92	5670	29.2	20.1	145.4	
MT	Columbia Falls	US 2	Arterial	02/92	12945	51.3	32.2	143.1	2 samples, range: 13.0 - 89.5
MT	East Helena	US 12	Arterial	02/03/92	7900	2.9	14.3	20.7	
MT	Thompson Falls	Preston	Local	02/22/92	920	0.5	18	2.6	
MT	Thompson Falls	Highway 200	Collector	02/22/92	5000	1.2	14.6	8.1	
MT	Kalispell	3rd btwn 2nd & 3rd	Local	03/15/92	450	40.2	11.9	338	

Table 3.2.2-4
Nonindustrial Paved Road Sampling Data[a]

ST	City	Sampling Location, Street, Road Name	Class[a]	Date	ADT[a]	Silt Loading (g/m^2)	Silt Content (%)	Total Loading (g/m^2)	Comments
MT	Kalispell	3rd btwn Main & 1st	Collector	03/15/92	2653	81.1	37.3	217.3	
MT	Kalispell	Main	Arterial	03/15/92	14730	16.5	32.1	51.3	
MT	Thompson Falls	Preston	Local	04/92	920	0.43	14.9	3.2	
MT	Thompson Falls	Highway 200	Collector	04/92	5000	0.8	18.2	4.7	3 samples, range: 0.4 - 1.0
MT	Kalispell	3rd btwn 2nd & 3rd	Local	04/26/92	450	20.9	45.8	45.5	
MT	Kalispell	3rd btwn Main & 1st	Collector	04/26/92	2653	19.2	50.9	37.7	
MT	Kalispell	Main	Arterial	04/26/92	14730	10.7	33.5	32.1	
MT	Kalispell	3rd btwn 2nd & 3rd	Local	05/92	450	8.3	35.6	23.5	3 samples, range: 6.6 - 10.3
MT	Kalispell	3rd btwn Main & 1st	Collector	05/92	2653	8.5	32.4	25.8	3 samples, range: 6.3 - 11.4
MT	Kalispell	Main	Arterial	05/92	14730	5.1	23.6	21.7	3 samples, range: 3.8 - 5.9
MT	Libby	W 4th St	Local	05/11/92	350	13.4	56.5	23.7	
MT	Libby	Main Ave 4th &	Collector	05/11/92	530	5.6	58.9	9.4	
MT	Libby	US 2	Arterial	05/92	12945	10.4	25.6	29.4	
MT	East Helena	Morton	Local	05/15/92	250	6.9	6.7	103	
MT	East Helena	Main St	Collector	05/15/92	2316	6.4	10.2	62.8	
MT	East Helena	US 12	Arterial	05/15/92	7900	1.2	6.9	17	
MT	Columbia Falls	Nucleus	Collector	05/25/92	5670	1	21.7	4.5	
MT	Missoula	Inez btwn 4th & 5th	Local	06/04/92	500	1	17.4	5.6	
MT	Missoula	Russel btwn 3rd & 4th	Collector	06/04/92	5270	15.2	14	108.4	
MT	Missoula	3rd btwn Prince & In	Arterial	06/04/92	12000	2	13.1	15.7	
CO	Denver	E. Colfax	Princ. Arterial[c]	03/89	1994[d]	0.21	2	19.9	4 samples, range: 0.04 - 0.47
CO	Denver	E. Colfax	Princ. Arterial[c]	04/89	2228[d]	0.73	1.7	106.7	18 samples, range: 0.08 - 1.76

Table 3.2.2-4
Nonindustrial Paved Road Sampling Data[a] (Page 8 of 10)

ST	City	Sampling Location, Street, Road Name	Class[a]	Date	ADT[a]	Silt Loading (g/m^2)	Silt Content (%)	Total Loading (g/m^2)	Comments
CO	Denver	York St	Princ. Arterial[c]	04/89	780[d]	0.86	1.2	74.8	2 samples, range: 0.83 - 0.89
CO	Denver	E. Belleview	Princ. Arterial[c]	04/89	-----	0.07	4.2	2	3 samples, range: 0.03 - 0.09
CO	Denver	I-225	Expressway[c]	04/89	4731[d]	0.02	3.6	0.4	3 samples, range: 0.01 - 0.02
CO	Denver	W. Evans	Princ. Arterial[c]	05/89	1905[d]	0.76	1.9	74	11 samples, range: 0.03 - 2.24
CO	Denver	W. Evans	Princ. Arterial[c]	06/89	1655[d]	0.71	1.2	66.1	12 samples, range: 0.07 - 3.34
CO	Denver	E. Louisiana	Minor Arterial[c]	06/89	515[d]	0.14	4.66	3.5	5 samples, range: 0.08 - 0.24
CO	Denver	E. Louisiana	Minor Arterial[c]	01/90	-----	1.44[e]	-----	-----	6 samples, range: 0.12 - 2.8
CO	Denver	E. Jewell Ave	Collector[c]	01/24/90	-----	2.24[e]	-----	-----	
CO	Denver	State Highway 36	Expressway[c]	01/30/90	-----	0.56[e]	-----	-----	2 samples, range: 0.56 - 0.56
CO	Denver	State Highway 36	Expressway[c]	02/01/90	-----	1.92[e]	-----	-----	4 samples, range: 1.92 - 1.92
CO	Denver	W. Evans Ave	Princ. Arterial[c]	02/03/90	-----	1.64[e]	-----	-----	2 samples, range: 1.64 - 1.64
CO	Denver	E. Mexico St	Local[c]	02/07/90	-----	2.58[e]	-----	-----	3 samples, range: 2.58 - 2.58
CO	Denver	E. Colfax Ave	Princ. Arterial[c]	02/90	-----	0.09[e]	-----	-----	16 samples, range: 0.02 - 0.17
CO	Denver	State Highway 36	Expressway[c]	03/90	-----	-----	-----	-----	7 samples
CO	Denver	E. Louisiana Ave	Minor Arterial[c]	03/10/90	-----	-----	-----	-----	3 samples
CO	Denver	W. Evans Ave	Princ. Arterial[c]	03/90	-----	1.27[e]	-----	-----	5 samples, range: 0.07 - 3.38
CO	Denver	W. Colfax Ave	Princ. Arterial[c]	03/90	-----	0.41[e]	-----	-----	21 samples, range: 0.04 - 2.61
CO	Denver	Parker Rd	Local[c]	04/90	-----	0.05[e]	-----	-----	6 samples, range: 0.01 - 0.11
CO	Denver	W. Byron Pl	Princ. Arterial[c]	04/90	-----	0.3[e]	-----	-----	6 samples, range: 0.21 - 0.35
CO	Denver	E. Colfax Ave	Princ. Arterial[c]	04/18/90	-----	0.21[e]	-----	-----	
UT	Salt Lake County	700 East	Arterial	[f]	42340	0.137	11.5	1.187	4 samples, range: 0.107 - 0.162
UT	Salt Lake County	State St	Collector	"	27140	0.288	17	1.692	4 samples, range: 0.212 - 0.357

Table 3.2.2-4
Nonindustrial Paved Road Sampling Data[a]

ST	City	Sampling Location, Street, Road Name	Class[a]	Date	ADT[a]	Silt Loading (g/m^2)	Silt Content (%)	Total Loading (g/m^2)	Comments
UT	Salt Lake County	I-80	Freeway	"	77040	0.023	21.4	0.1	5 samples, range: 0.011 - 0.034
UT	Salt Lake County	I-15	Freeway	"	146180	0.096	23.5	0.419	6 samples, range: 0.078 - 0.126
UT	Salt Lake County	400 East	Local	"	5000	1.967	4.07	46.043	14 samples, range: 0.177 - 5.772
NV	Las Vegas	Lake Mead	Major	07/15/87	-----	0.81	12.4	6.51	
NV	Las Vegas	Perliter	Local	07/15/87	-----	2.23	31.2	7.14	
NV	Las Vegas	Bruce	Collector	07/15/87	-----	1.64	26.1	6.3	
NV	Las Vegas	Stewart	Major	09/29/87	-----	0.38	24	1.63	3 samples, range: 0.24 - 0.46
NV	Las Vegas	Ambler	Local	09/29/87	-----	1.38	23	6.32	3 samples, range: 0.64 - 2.00
NV	Las Vegas	28th St	Collector	09/29/87	-----	0.52	15.8	3.4	3 samples, range: 0.51 - 0.54
NV	Las Vegas	Lake Mead	Major	10/07/87	-----	0.19	14.9	1.26	2 samples, range: 0.17 - 0.20
NV	Las Vegas	Perliter	Local	10/07/87	-----	1.5	31.9	4.76	2 samples, range: 1.48 - 1.52
NV	Las Vegas	Bruce	Collector	10/07/87	-----	0.9	24.1	3.74	2 samples, range: 0.76 - 1.03
AZ	Phoenix	Broadway	Arterial	"	-----	0.127	12.2	1.071	
AZ	Phoenix	South Central	Arterial	"	-----	0.085	5	1.726	
AZ	Phoenix	Indian School & 28th	Arterial	"	-----	0.035	3.1	1.021	
AZ	Glendale	43rd & Vista	Arterial	"	-----	0.042	3.9	1.049	
AZ	Glendale	59th & Peoria	Arterial	"	-----	0.099	8.2	1.183	
AZ	Mesa	Mesa Drive	Arterial	"	-----	0.099	8.9	1.085	
AZ	Mesa	E. McKellips & Olive	Arterial	"	-----	0.014	17	0.092	
AZ	Phoenix	17th & Highland	Collector	"	-----	0.028	13.4	0.232	
AZ	Mesa	3rd & Miller	Collector	"	-----	0.07	11.8	0.627	
AZ	Phoenix	Avalon & 25th	Collector	"	-----	0.528	11.1	4.79	
AZ	Phoenix	Apache	Collector	"	-----	0.282	6.4	4.367	

Table 3.2.2-4
Nonindustrial Paved Road Sampling Data[a]

ST	City	Sampling Location, Street, Road Name	Class[a]	Date	ADT[a]	Silt Loading (g/m^2)	Silt Content (%)	Total Loading (g/m^2)	Comments
AZ	Phoenix	N. 28th St & E. Glenrosa	Collector	"	-----	0.035	2.3	1.479	
AZ	Pima County	6th Ave	Collector	"	-----	1.282	6.417	19.961	
AZ	Pima County	Speedway Blvd	Arterial	"	-----	0.401	8.117	4.937	
AZ	Pima County	22nd St	Arterial	"	-----	0.028	16.529	0.176	
AZ	Pima County	Amklam Rd	Collector	"	-----	0.014	5.506	0.197	
AZ	Pima County	Fort Lowel Rd	Arterial	"	-----	0.113	3.509	3.268	
AZ	Pima County	Oracle Rd	Arterial	"	-----	0.014	1.556	0.725	
AZ	Pima County	Inn Rd	Arterial	"	-----	0.021	18.756	0.127	
AZ	Pima County	Orange Grove	Arterial	"	-----	0.162	21.989	0.725	
AZ	Pima County	La Canada	Arterial	"	-----	0.106	3.975	2.571	
KS	Kansas City	7th	Arterial	02/80	-----	0.29	6.8	4.2	3 samples, range: 0.15 - 0.46
MO	Kansas City	Volker	Arterial	02/80	-----	0.67	20.1	3.5	3 samples, range: 0.43 -1.00
MO	Kansas City	Rockhill	Arterial	02/80	-----	0.68	21.7	3.3	
KS	Tonganoxie	4th	Collector	03/80	-----	2.5	14.5	17.1	
KS	Kansas City	7th	Arterial	03/80	-----	0.29	12.2	2.4	
MO	St. Louis	I-44	Expressway	05/80	-----	0.02	-----	-----	4 samples
MO	St. Louis	Kingshighway	Collector	05/80	-----	0.08	10.9	0.7	3 samples, range: 0.05 - 0.11
IL	Granite City	24th	Arterial	05/80	-----	0.78	6.4	12.3	2 samples, range: 0.73 - 0.83
IL	Granite City	Benton	Collector	05/80	-----	0.93	8.6	10.8	
MN	Duluth	US 53 (northbound lanes)	Highway	03/19/92	5000	0.23	28	1.94	8 samples, range: 0.04 - 0.77
MN	Duluth	US 53 (southbound lanes)	Highway	02/26/92	5000	0.24	13.4	2.3	5 samples, range: 0.05 - 0.37

[a] References 7, and 13-20. Classifications and values as given in reference, except as noted. ADT = Average Daily Traffic
[b] ----- = Information not available.
[c] Reference 16.
[d] Value given is the hourly traffic rate observed during testing. ADT values not reported.
[e] Samples are said to wet sieved. Wet sieving results are not directly comparable to those for the dry sieving described in AP-42 Appendix C.
[f] No specific date given for sampling. Samples are said to be "post storm".
[g] No specific date given for sampling.

References

1. D. R. Dunbar. *Resuspension of Particulate Matter*, EPA-450/2-76-031, U.S. Environmental Protection Agency, Research Triangle Park, NC, March 1976.

2. R. Bohn, et al. *Fugitive Emissions from Integrated Iron and Steel Plants*, EPA-600/2-78-050, U.S. Environmental Protection Agency, Cincinnati, OH, March 1978.

3. C. Cowherd, Jr., et al. *Iron and Steel Plant Open Dust Source Fugitive Emission Evaluation*, EPA-600/2-79-103, U.S. Environmental Protection Agency, Cincinnati, OH, May 1979.

4. C. Cowherd, Jr., et al. *Quantification of Dust Entrainment from Paved Roadways*, EPA-450/3-77-027, U.S. Environmental Protection Agency, Research Triangle Park, NC, July 1977.

5. *Size Specific Particulate Emission Factors for Uncontrolled Industrial and Rural Roads*, EPA Contract No. 68-02-3158, Midwest Research Institute, Kansas City, MO, September 1983.

6. T. Cuscino, Jr., et al. *Iron and Steel Plant Open Source Fugitive Emission Control Evaluation*, EPA-600/2-83-110, U.S. Environmental Protection Agency, Cincinnati, OH, October 1983.

7. C. Cowherd, Jr., and P. J. Englehart. *Paved Road Particulate Emissions*, EPA-600/7-84-077, U.S. Environmental Protection Agency, Cincinnati, OH, July 1984.

8. C. Cowherd, Jr., and P. J. Englehart. *Size Specific Particulate Emission Factors for Industrial and Rural Roads*, EPA-600/7-85-038, U.S. Environmental Protection Agency, Cincinnati, OH, September 1985.

9. *Emission Factor Documentation for AP-42, Sections 11.2.5 and 11.2.6–Paved Roads*, EPA Contract No. 68-D0-0123, Midwest Research Institute, Kansas City, MO, March 1993.

10. *Evaluation of Open Dust Sources in the Vicinity of Buffalo, New York*, EPA Contract No. 68-02-2545, Midwest Research Institute, Kansas City, MO, March 1979.

11. *PM-10 Emission Inventory of Landfills in the Lake Calumet Area*, EPA Contract No. 68-02-3891, Midwest Research Institute, Kansas City, MO, September 1987.

12. *Chicago Area Particulate Matter Emission Inventory–Sampling and Analysis*, Contract No. 68-02-4395, Midwest Research Institute, Kansas City, MO, May 1988.

13. *Montana Street Sampling Data*, Montana Department of Health and Environmental Sciences, Helena, MT, July 1992.

14. *Street Sanding Emissions and Control Study*, PEI Associates, Inc., Cincinnati, OH, October 1989.

15. *Evaluation of PM-10 Emission Factors for Paved Streets*. Harding Lawson Associates, Denver, CO, October 1991.

16. *Street Sanding Emissions and Control Study*, RTP Environmental Associates, Inc., Denver, CO, July 1990.

17. *Post-storm Measurement Results–Salt Lake County Road Dust Silt Loading Winter 1991/92 Measurement Program*, Aerovironment, Inc., Monrovia, CA, June 1992.

18. Written communication from Harold Glasser, Department of Health, Clark County (NV).

19. *PM-10 Emissions Inventory Data for the Maricopa and Pima Planning Areas*, EPA Contract No. 68-02-3888, Engineering-Science, Pasadena, CA, January 1987.

20. *Characterization of PM-10 Emissions from Antiskid Materials Applied to Ice- and Snow-Covered Roadways*, EPA Contract No. 68-D0-0137, Midwest Research Institute, Kansas City, MO, October 1992.

21. C. Cowherd, Jr., et al. *Control of Open Fugitive Dust Sources*, EPA-450/3-88-008, U.S. Environmental Protection Agency, Research Triangle Park, NC, September 1988.

3.2.3 Fugitive Dust from Heavy Construction Operations

3.2.3 Fugitive Dust from Heavy Construction Operations

Source of Emissions Data

The following information was obtained from:

U.S. Environmental Protection Agency. 1995. *Compilation of Air Pollutant Emission Factors, Volume I: Stationary Point and Area Sources* (Fifth Edition–DRAFT). Section 13.2.3.

Estimating Emissions

General Description.[1,2] Heavy construction is a source of dust emissions that may have substantial temporary impact on local air quality. Building and road construction are two examples of construction activities with high emissions potential. Emissions during the construction of a building or road can be associated with land clearing, drilling and blasting, ground excavation, cut and fill operations (that is, earth moving), and construction of a particular facility itself. Dust emissions often vary substantially from day to day, depending on the level of activity, the specific operations, and the prevailing meteorological conditions. A large portion of the emissions results from equipment traffic over temporary roads at the construction site.

The temporary nature of construction differentiates it from other fugitive dust sources as to estimation and control of emissions. Construction consists of a series of different operations, each with its own duration and potential for dust generation. In other words, emissions from any single construction site can be expected to (1) have a definable beginning and an end and (2) vary substantially over different phases of the construction process. This is in contrast to most other fugitive dust sources, where emissions are either relatively steady or follow a discernible annual cycle. Furthermore, there is often a need to estimate areawide construction emissions, without regard to the actual plans of any individual construction project. For these reasons, following are methods by which either areawide or site-specific emissions may be estimated.

Emission Factor Data. The quantity of dust emissions from construction operations is proportional to the area of land being worked and to the level of construction activity. By analogy to the parameter dependence observed for other similar fugitive dust sources,[1] one can expect emissions from heavy construction operations to be positively correlated with the silt content of the soil (that is, particles smaller than 75 micrometers in diameter), as well as with the speed and weight of the average vehicle, and to be negatively correlated with the soil moisture content.

Only one set of field studies has been performed that attempts to relate the emissions from construction directly to an emission factor.[1-2] Based on field measurements of TSP

concentrations surrounding apartment and shopping center construction projects, the approximate emission factors for construction activity operations are:

$$E = 2.69 \text{ Mg/hectare/month of activity}$$
$$E = 1.2 \text{ tons/acre/month of activity}$$

These values are most useful for developing estimates of overall emissions from construction scattered throughout a geographical area. The value is most applicable to construction operations with medium activity level, moderate silt contents, and semiarid climate. Test data were not sufficient to derive the specific dependence of dust emissions on correction parameters. Because the above emission factor is referenced to TSP, the use of this factor to estimate PM_{10} emissions will result in conservatively high estimates. Also, because derivation of the factor assumes that construction activity occurs 30 days per month, the above estimate is somewhat conservatively high for TSP as well.

Although the equation above represents a relatively straightforward means of preparing an areawide emission inventory, at least two features limit its usefulness for specific construction sites. First, the conservative nature of the emission factor may result in too high an estimate for PM_{10} to be of much use for a specific site under consideration. Second, the equation provides neither information about which particular construction activities have the greatest emission potential nor guidance for developing an effective dust control plan.

For these reasons, it is strongly recommended that when emissions are to be estimated for a particular construction site, the construction process be broken down into component operations. (Note that many general contractors typically employ planning and scheduling tools, such as the critical path method, that make use of different sequential operations to allocate resources.) This approach to emission estimation uses a unit or phase method to consider the more basic dust sources of vehicle travel and material handling. That is to say, the construction project is viewed as consisting of several operations, each involving traffic and material movements, and emission factors from other *AP-42* sections are used to generate estimates. Table 3.2.3-1 displays the dust sources involved with construction, along with the recommended emission factors.[3]

In addition to the onsite activities shown in Table 3.2.3-1, substantial emissions are possible because of material tracked out from the site and deposited on adjacent paved streets. Because all traffic passing the site (not just traffic associated with the construction) can resuspend the deposited material, this "secondary" source of emissions may be far more important than all the dust sources actually within the construction site. Furthermore, this secondary source will be present during all construction operations. Persons developing construction site emission estimates must consider the potential for increased adjacent emissions from offsite paved roadways (see Section 3.2.2, "Vehicle Traffic on Paved Roads"). High wind events also can lead to emissions from cleared land and material stockpiles. Section 13.2.6 of *AP-42* (EPA, 1985), "Industrial Wind Erosion," presents an estimation methodology that can be used for such sources at construction sites.

Emission Calculations. Total suspended particulate emissions from construction activities (medium activity level) scattered throughout a geographical area with moderate silt contents and a semiarid climate are calculated using the following equation:

$$E = EF * A$$

where E = Monthly TSP emissions (tons of TSP/hour)
EF = Emission factor (tons of TSP/construction area in acres/month)
A = Exposed construction area (acres)

Example

The construction activities of four new campgrounds in Utah are expected to affect 200 acres. Of this, approximately 100 acres will be fully or partially exposed and 100 acres will be covered by buildings, paved roads, and parking lots. If all 100 acres are exposed for a period of 1 month, dust emissions will average approximately as follows:

$$E = 1.2 \frac{tons\ TSP}{acres * month} * 100\ acres$$

$$= 120 \frac{tons\ TSP}{month}$$

Mitigation Techniques[4]

Because of the relatively short-term nature of construction activities, some control measures are more cost-effective than others. Wet suppression and wind speed reduction are two common methods used to control open dust sources at construction sites, because a source of water and materials for wind barriers tends to be readily available on a construction site. However, several other forms of dust control are available.

Table 3.2.3-2 displays each of the preferred control measures, by dust source.[3-4] Because most of the controls listed in the table modify independent variables in the emission factor models, the effectiveness can be calculated by comparing controlled and uncontrolled emission estimates from Table 3.2.3-1. Additional guidance on controls is provided in the *AP-42* sections from which the recommended emission factors were taken, as well as in other documents, such as Reference 4.

Table 3.2.3-1
Recommended Emission Factors for Construction Operations[a]

Construction Phase	Dust-Generating Activities	Recommended Emission Factor	Comments	Rating Adjustment[b]
I. Demolition and debris removal	1. Demolition of buildings or other (natural) obstacles such as trees, boulders, etc.			
	a. Mechanical dismemberment ("headache ball") of existing structures	NA		—
	b. Implosion of existing structures	NA		—
	c. Drilling and blasting of soil	Drilling factor in Table 11.24-4 (AP-42) Blasting factor NA	 Blasting factor in Table 11.24-1, -2 (AP-42) not considered appropriate for general construction activities	–1 NA
	d. General land clearing	Dozer equation (overburden) in Table 11.24-1, -2 (AP-42)		–1/–2[c]
	2. Loading of debris into trucks	Material handling factor in Section 13.2.2 (AP-42)		–0/–1[c]
	3. Truck transport of debris	Unpaved road emission factor in Section 3.2.1, or Paved road emission factor in Section 3.2.2		–0/–1[c] –0/–1[c]
	4. Truck unloading of debris	Material handling factor in Section 13.2.2 (AP-42)	May occur offsite	–0/–1[c]

Table 3.2.3-1
Recommended Emission Factors for Construction Operations[a]

Construction Phase	Dust-Generating Activities	Recommended Emission Factor	Comments	Rating Adjustment[b]
II. Site Preparation (earth moving)	1. Bulldozing	Dozer equation (overburden) in Table 11.24-1, -2 (AP-42)		–1/–2[c]
	2. Scrapers unloading topsoil	Scraper unloading factor in Table 11.24-4 (AP-42)		–1
	3. Scrapers in travel	Scraper (travel mode) expression in Table 11.24-1, -2 (AP-42)		–0/–1[c]
	4. Scrapers removing topsoil	5.7 kg/VKT (20.2 lb/VMT)		E[d]
	5. Loading of excavated material into trucks	Material handling factor in Section 13.2.2 (AP-42)		–0/–1[c]
	6. Truck dumping of fill material, road base, or other materials	Material handling factor in Section 13.2.2 (AP-42)	May occur off site	–0/–1[c]
	7. Compacting	Dozer equation in Table 11.24-1, -2 (AP-42)	Emission factor downgraded because of differences in operating equipment	–1/–2[c]
	8. Motor grading	Grading equation in Table 11.24-1, -2 (AP-42)		–1/–2[c]

Table 3.2.3-1
Recommended Emission Factors for Construction Operations[a]

Construction Phase	Dust-Generating Activities	Recommended Emission Factor	Comments	Rating Adjustment[b]
III. General Construction	1. Vehicular traffic	Unpaved road emission factor in Section 3.2.1, or Paved road emission factor in Section 3.2.2		–0/–1[c] –0/–1[c]
	2. Portable plants			
	2a. Crushing	Factors for similar material/operations in Section 11 (AP-42)		–1/–2[c]
	2b. Screening	Factors for similar material/operations in Section 11 (AP-42)		–1/–2[c]
	2c. Material transfers	Material handling factor in Section 13.2.2 (AP-42)		–0/–1[c]
	2d. Other operations	Factors for similar material/operations in Section 11 (AP-42)		—

[a]NA = Not Applicable.
[b]Refers to how many additional letters the emission factor should be downrated (beyond the guidance given in the other sections of AP-42) for application to construction activities. For example, "–2" means that an A-rated factor should be considered of C quality in estimating construction emissions. All emission factors assumed to have site-specific input values; otherwise, additional downgrading of one letter should be employed. Note that no rating can be lower than E.
[c]First value for cases with independent variables within range given in AP-42 section; second value for cases with at least one variable outside the range.
[d]Rating for emission factor given. Reference 5.
[e]In the event that individual operations cannot be identified, one may very conservatively overestimate PM_{10} emissions by using Equation 1.

Table 3.2.3-2
Control Options For General Construction Open Sources of PM_{10}

Emission Source	Recommended Control Method(s)
Debris handling	Wind speed reduction Wet suppression[a]
Truck transport[b]	Wet suppression Paving Chemical stabilization[c]
Bulldozers	Wet suppression[d]
Pan scrapers	Wet suppression of travel routes
Cut/fill material handling	Wind speed reduction Wet suppression
Cut/fill haulage	Wet suppression Paving Chemical stabilization
General construction	Wind speed reduction Wet suppression Early paving of permanent roads

[a]Dust control plans should contain precautions against watering programs that confound trackout problems.
[b]Loads could be covered to avoid loss of material in transport, especially if material is transported offsite.
[c]Chemical stabilization is usually cost-effective for relatively long-term or semipermanent unpaved roads.
[d]Excavated materials may already be moist and not require additional wetting. Furthermore, most soils are associated with an "optimum moisture" for compaction.

References

1. C. Cowherd, Jr., et al. *Development of Emissions Factors for Fugitive Dust Sources*, EPA-450/3-74-03, U.S. Environmental Protection Agency, Research Triangle Park, NC, June 1974.

2. G. A. Jutze, et al. *Investigation of Fugitive Dust Sources Emissions and Control*, EPA-450/3-74-036a, U.S. Environmental Protection Agency, Research Triangle Park, NC, June 1974.

3. *Background Documentation for AP-42 Section 11.2.4, Heavy Construction Operations*, EPA Contract No. 69-D0-0123, Midwest Research Institute, Kansas City, MO, April 1993.

4. C. Cowherd, et al. *Control of Open Fugitive Dust Sources*, EPA-450/3-88-008, U. S. Environmental Protection Agency, Research Triangle Park, NC, September 1988.

5. M. A. Grelinger, et al. *Gap Filling PM-10 Emission Factors for Open Area Fugitive Dust Sources*, EPA-450/4-88-003, U. S. Environmental Protection Agency, Research Triangle Park, NC, March 1988.

3.2.4 Fugitive Dust from Aggregate Handling and Storage Piles

3.2.4 Fugitive Dust from Aggregate Handling and Storage Piles

Source of Emissions Data

The following information was obtained from:

U.S. Environmental Protection Agency. 1985 and ff. *Compilation of Air Pollutant Emission Factors, Volume I: Stationary Point and Area Sources* (Fourth Edition). Section 13.2.2.

Estimating Emissions

General Description. Inherent in operations that use minerals in aggregate form is the maintenance of outdoor storage piles. Storage piles are usually left uncovered, partially because of the need for frequent material transfer into or out of storage.

Dust emissions occur at several points in the storage cycle, such as material loading onto the pile, disturbances by strong wind currents, and loadout from the pile. The movement of trucks and loading equipment in the storage pile area is also a substantial source of dust.

Emissions and Correction Parameters. The quantity of dust emissions from aggregate storage operations varies with the volume of aggregate passing through the storage cycle. Emissions also depend on three parameters of the condition of a particular storage pile: age of the pile, moisture content, and proportion of aggregate fines.

When freshly processed aggregate is loaded onto a storage pile, the potential for dust emissions is at a maximum. Fines are easily disaggregated and released to the atmosphere upon exposure to air currents, either from aggregate transfer itself or from high winds. As the aggregate pile weathers, however, potential for dust emissions is greatly reduced. Moisture causes aggregation and cementation of fines to the surfaces of larger particles. Any significant rainfall soaks the interior of the pile, and then the drying process is very slow.

Silt (particles equal to or less than 75 microns in diameter) content is determined by measuring the portion of dry aggregate material that passes through a 200-mesh screen, using ASTM-C-136 method.[1] Table 3.2.4-1 summarizes measured silt and moisture values for selected industrial aggregate materials.

Emission Factor Data. Total dust emissions from aggregate storage piles result from several distinct source activities within the storage cycle:

- Loading of aggregate onto storage piles (batch or continuous drop operations)
- Equipment traffic in storage area
- Wind erosion of pale surfaces and ground areas around piles
- Loadout of aggregate for shipment or for return to the process stream (batch or continuous drop operations)

Table 3.2.4-1
Typical Silt and Moisture Contents of Materials at Various Industries[a]

Industry	No. of Facilities	Material	Silt Content (%)			Moisture Content (%)		
			No. of Samples	Range	Mean	No. of Samples	Range	Mean
Stone quarrying and processing	2	Crushed limestone	2	1.3 - 1.9	1.6	2	0.3 - 1.1	0.7
		Various limestone products	8	0.8 - 14	3.9	8	0.46 - 5.0	2.1
Taconite mining and processing	1	Pellets	9	2.2 - 5.4	3.4	7	0.05 - 2.0	0.9
		Tailings	2	NA	11	1	-	0.4
Western surface coal mining	4	Coal	15	3.4 - 16	6.2	7	2.8 - 20	6.9
		Overburden	15	3.8 - 15	7.5	0	-	-
		Exposed ground	3	5.1 - 21	15	3	0.8 - 6.4	3.4

[a]References 1 - 8. NA = Not Available.

Adding aggregate material to a storage pile or removing it usually involves dropping the material onto a receiving surface. Truck dumping on the pile or loading out from the pile to a truck with a front-end loader are examples of batch drop operations. Adding material to the pile by a conveyor stacker is an example of a continuous drop operation.

The quantity of particulate emissions generated by either type of drop operation, per kg (ton) of material transferred, may be estimated, with a rating of A, using the following empirical expression:[9]

$$E = k\,(0.0016)\,\frac{\left(\frac{U}{2.2}\right)^{1.3}}{\left(\frac{M}{2}\right)^{1.4}}\ \text{(kg/Mg)}$$

$$E = k\,(0.0032)\,\frac{\left(\frac{U}{5}\right)^{1.3}}{\left(\frac{M}{2}\right)^{1.4}}\ \text{(lb/ton)}$$

where:
- E = emission factor
- k = particle size multiplier (dimensionless)
- U = mean wind speed, m/s (mph)
- M = material moisture content (%)

The particle size multiplier in the equation, k, varies with aerodynamic particle size range, as follows:

Aerodynamic Particle Size Multiplier (k) for Equation				
< 30 μm	< 15 μm	< 10 μm	< 5 μm	< 2.5 μm
0.74	0.48	0.35	0.20	0.11

The equation retains the assigned quality rating if applied within the ranges of source conditions that were tested in developing the equation, as follows. Note that silt content is included, even though silt content does not appear as a correction parameter in the equation. While it is reasonable to expect that silt content and emission factors are interrelated, no significant correlation between the two was found during the derivation of the equation, probably because most tests with high silt contents were conducted under lower winds, and vice versa. It is recommended that estimates from the equation be reduced one quality rating level if the silt content used in a particular application falls outside the range given:

Ranges of Source Conditions for Equation

Silt Content (%)	Moisture Content (%)	Wind Speed	
		(m/s)	(mph)
0.44 - 19	0.25 - 4.8	0.6 - 6.7	1.3 - 15

To retain the quality rating of the equation when it is applied to a specific facility, reliable correction parameters must be determined for specific sources of interest. The field and laboratory procedures for aggregate sampling are given in Reference 2. In the event that site-specific values for correction parameters cannot be obtained, the appropriate mean from Table 3.2.4-1 may be used, but the quality rating of the equation is reduced by one letter.

For emissions from equipment traffic (trucks, front-end loaders, dozers, etc.) traveling between or on piles, it is recommended that the equations for vehicle traffic on unpaved surfaces be used (see Section 3.2.1, "Vehicle Traffic on Unpaved Roads"). For vehicle travel between storage piles, the silt value(s) for the areas among the piles (which may differ from the silt values for the stored materials) should be used.

Worst-case emissions from storage pile areas occur under dry, windy conditions. Worst-case emissions from materials-handling operations may be calculated by substituting into the equation appropriate values for aggregate material moisture content and for anticipated wind speeds during the worst case averaging period, usually 24 hours. The treatment of dry conditions for Section 3.2.1, "Vehicle Traffic on Unpaved Roads," follows the methodology described in that section centering on parameter p. A separate set of nonclimatic correction parameters and source extent values corresponding to higher than normal storage pile activity also may be justified for the worst-case averaging period.

Emission Calculations. The equation provided above produces an emission factor that can be used to estimate dust emissions from transferring aggregate material onto and from storage piles. The following example illustrates how to select data to be used in the equation. The result of the calculation, an emission factor, will then be used to estimate daily emissions for the given scenario.

Example

Approximately 160 tons of crushed limestone are expected to be processed daily at a temporary stone quarrying facility. Assuming that site-specific data are not available, estimate the daily PM_{10} emissions from loadout operations from a storage pile. To perform the calculation, the following assumptions were made:

k = 0.35
U = 5 m/s
M = 0.7% (from Table 3.2.4-1)

$$E = 0.35\ (0.0016)\ \frac{\left(\frac{5}{2.2}\right)^{1.3}}{\left(\frac{0.7}{2}\right)^{1.4}}\ (kg/Mg)$$

$$= 0.0071\ kg\ of\ PM_{10}\ per\ Mg\ of\ Limestone\ Handled$$

Please note: The mean material moisture content used in the above equation is not site specific; therefore, the rating of the emission factor must be reduced one letter (from A to B).

Daily emissions can be estimated with the following equation:

$$E = \left(EF,\ \frac{kg}{Mg}\right) \cdot (Material\ Handled,\ Mg/day)$$

Substituting the values for the emission factor and the amount of limestone handled daily, emissions of PM_{10} are estimated to be 1.03 kg per day.

Mitigation Techniques[10-11]

Watering and the use of chemical wetting agents are the principal means for control of aggregate storage pile emissions. Enclosure or covering of inactive piles to reduce wind erosion can also reduce emissions. Watering is useful mainly to reduce emissions from vehicle traffic in the storage pile area. Watering of the storage piles themselves typically has only a very temporary slight effect on total emissions. A much more effective technique is to apply chemical agents (such as surfactants) that permit more extensive wetting. Continuous chemical treating of material loaded onto piles, coupled with watering or treatment of roadways, can reduce total particulate emissions from aggregate storage operations by up to 90 percent.[10]

References

1. C. Cowherd, Jr., et al., *Development of Emission Factors for Fugitive Dust Sources*, EPA-450/3-74-037, U.S. Environmental Protection Agency, Research Triangle Park, NC, June 1974.

2. C. Cowherd, Jr., et al., *Iron and Steel Plant Open Dust Source Fugitive Emission Evaluation*, EPA-600/2-79-103, U.S. Environmental Protection Agency, Cincinnati, OH, May 1979.

3. *Evaluation of Open Dust Sources in the Vicinity of Buffalo, New York*, EPA Contract No. 68-02-2545, Midwest Research Institute, Kansas City, MO, March 1979.

4. C. Cowherd, Jr., and T. Cuscino, Jr., *Fugitive Emissions Evaluation*, MRI-4343-L, Midwest Research Institute, Kansas City, MO, February 1977.

5. T. Cuscino, Jr., et al., *Taconite Mining Fugitive Emissions Study*, Minnesota Pollution Control Agency, Roseville, MN, June 1979.

6. *Improved Emission Factors for Fugitive Dust from Western Surface Coal Mining Sources*, 2 Volumes, EPA Contract No. 68-03-2924, PEDCo Environmental, Kansas City, MO, and Midwest Research Institute, Kansas City, MO, July 1981.

7. *Determination of Fugitive Coal Dust Emissions from Rotary Railcar Dumping*, TRC, Hartford, CT, May 1984.

8. *Chicago Area Particulate Matter Emission Inventory—Sampling and Analysis*, EPA Contract 68-02-4395, Midwest Research Institute, Kansas City, MO, May 1988.

9. *Update of Fugitive Dust Emission Factors in AP-42 Section 11.2*, EPA Contract 68-02-3891, Midwest Research Institute, Kansas City, MO, July 1987.

10. G. A. Jutze, et al., *Investigation of Fugitive Dust Sources Emissions and Control*, EPA-450/3-74-036a, U.S. Environmental Protection Agency, Research Triangle Park, NC, June 1974.

11. C. Cowherd, Jr., et al., *Control of Open Fugitive Dust Sources*, EPA-450/3-88-008, U.S. Environmental Protection Agency, Research Triangle Park, NC, September 1988.

3.3.1 Gasoline and Diesel Industrial Engines

3.3.1 Gasoline and Diesel Industrial Engines

Source of Emissions Data

The following information was obtained from:

U.S. Environmental Protection Agency. 1985 and ff. *Compilation of Air Pollutant Emission Factors, Volume I: Stationary Point and Area Sources* (Fourth Edition). Section 3.3.

Estimating Emissions

General Description. The engine category addressed in this section covers a wide variety of industrial applications of both gasoline and diesel internal combustion engines, such as aerial lifts, fork lifts, mobile refrigeration units, generators, pumps, industrial sweepers/ scrubbers, material handling equipment (such as conveyors), and portable well-drilling equipment. The rated power of these engines covers a rather substantial range: up to 186 kilowatts (kW) (250 horsepower [hp]) for gasoline engines and up to 447 kW (600 hp) for diesel engines. (Diesel engines greater than 600 hp are covered in Section 3.3.3, "Large Diesel Engines." Understandably, substantial differences in engine duty cycles exist. It was necessary, therefore, to make reasonable assumptions concerning usage in order to formulate some of the emission factors.

All reciprocating internal combustion (IC) engines operate by the same basic process. A combustible mixture is first compressed in a small volume between the head of a piston and its surrounding cylinder. The mixture is then ignited, and the resulting high-pressure products of combustion push the piston through the cylinder. This movement is converted from linear to rotary motion by a crankshaft. The piston returns, pushing out exhaust gases, and the cycle is repeated.

There are two methods used for stationary reciprocating IC engines: compression ignition (CI) and spark ignition (SI). This section deals with both types of reciprocating internal combustion engines.

In compression ignition engines, combustion air is first compression-heated in the cylinder, and diesel fuel oil is then injected into the hot air. Ignition is spontaneous as the air is above the auto-ignition temperature of the fuel. Spark ignition engines initiate combustion by the spark of an electrical discharge. Usually the fuel is mixed with the air in a carburetor (for gasoline) or at the intake valve (for natural gas), but occasionally the fuel is injected into the compressed air in the cylinder. All diesel-fueled engines are compression ignited and all gasoline-fueled engines are spark ignited.

CI engines usually operate at a higher compression ratio (ratio of cylinder volume when the piston is at the bottom of its stroke to the volume when it is at the top) than SI engines because fuel is not present during compression. Hence there is no danger of premature auto-

ignition. Since engine thermal efficiency rises with increasing pressure ratio (and pressure ratio varies directly with compression ratio), CI engines are more efficient than SI engines. This increased efficiency is gained at the expense of poorer response to load changes and a heavier structure to withstand the higher pressures.

Emission Factor Data. The best method for calculating emissions is on the basis of "brake-specific" emission factors (g/hp-hr or g/kW-hr). Emissions are calculated by taking the product of the brake-specific emission factor, the usage in hours (that is, hours per year or hours per day), the power available (rated power), and the load factor (the power actually used divided by the power available). An alternative method of estimating emissions is to take the product of the emission factor based on fuel input (lb/MMBtu or ng/J) and the fuel usage.

Once reasonable usage and duty cycles for this category were ascertained, emission values were aggregated to arrive at the factors presented in Tables 3.3.1-1 (English units) and 3.3.1-2 (metric units) for criteria and organic pollutants. Emissions data for a specific design type were weighted according to estimated material share for industrial engines. The emission factors in this table are most appropriately applied to a population of industrial engines rather than to an individual power plant because of their aggregate nature.

Emission Calculations. Pollutant emissions from industrial engines can be calculated on the basis of "brake-specific" emission factors using the following equation:

$$E = EF \cdot U \cdot P \cdot L \cdot \left(\frac{1\ lb}{454\ grams}\right)$$

where E = Daily pollutant emissions, lb per day
EF = Emission factor, grams per hp-hr (grams per kW-hr)
U = Usage, hours per day
P = Power available, horsepower (kilowatts)
L = Load factor, dimensionless

Example

Construction equipment at a proposed building site will be powered by a 500-hp diesel-fueled generator. Calculate the carbon monoxide emissions from this engine assuming the estimated use of the engine is 8 hp per day and the load factor is 0.87.

$$E = \left(3.03 \frac{grams}{hp \cdot hour}\right) \cdot \left(8 \frac{hours}{day}\right) \cdot (500\ hp) \cdot (0.87) \cdot \left(\frac{1\ lb}{454\ grams}\right)$$

$$= 23.2 \frac{lb}{day}\ of\ CO$$

Hazardous Air Pollutants, Trace Elements, and Ozone. Table 3.3.1-3 shows unweighted speciated organic compound and air toxic emissions factors based upon only two engines. Their inclusion in this section is intended only for rough order-of-magnitude estimates. Emission estimates can be calculated by taking the product of the emission factor and the rate of fuel consumption (based on the heating value of the fuel).

Mitigation Techniques

Table 3.3.1-4 shows a summary of various diesel emission reduction technologies (some of which may be applicable to gasoline engines). These technologies are categorized into fuel modifications, engine modifications, and exhaust after treatments. Current data are insufficient to quantify the results of the modifications. Table 3.3.1-4 provides general information on the trends of changes on selected parameters.

Table 3.3.1-1
Emission Factors for Uncontrolled Gasoline and Diesel Industrial Engines[a]
(English Units)

(Source Classification Codes)

Pollutant [Rating][b]	Gasoline Fuel (SCC 20200301, 20300301)		Diesel Fuel (SCC 20200102, 20300101)	
	[grams/hp-hr] (power output)	[lb/MMBtu] (fuel input)	[grams/hp-hr] (power output)	[lb/MMBtu] (fuel input)
NO_x [D]	5.16	1.63	14.0	4.41
CO [D]	199	62.7	3.03	0.95
SO_x [D]	0.268	0.084	0.931	0.29
Particulate [D]	0.327	0.10	1.00	0.31
CO_2 [B][c]	493	155	525	165
Aldehydes [D]	0.22	0.07	0.21	0.07
Hydrocarbons				
Exhaust [D]	6.68	2.10	1.12	0.35
Evaporative [E]	0.30	0.09	0.00	0.00
Crankcase [E]	2.20	0.69	0.02	0.01
Refueling [E]	0.49	0.15	0.00	0.00

[a]Data based on uncontrolled levels for each fuel from References 1, 3 and 6. When necessary, the average brake specific fuel consumption (BSFC) value was used to convert from g/hp-hr to lb/MMBtu was 2547 Btu/hp-hr.
[b]"D" and "E" rated emission factors are most appropriate when applied to a population of industrial engines rather than to an individual power plant, due to the aggregate nature of the emissions data.
[c]Based on assumed 100 percent conversion of carbon in fuel to CO_2 with 87 weight percent carbon in diesel, 86 weight percent carbon in gasoline, average brake-specific fuel consumption of 7,000 Btu/hp-hr, diesel heating value of 19,300 Btu/lb, and gasoline heating value of 20,300 Btu/lb.

Table 3.3.1-2
Emission Factors for Uncontrolled Gasoline and Diesel Industrial Engines[a]
(Metric Units)

(Source Classification Codes)

Pollutant [Rating][b]	Gasoline Fuel (SCC 20200301, 20300301)		Diesel Fuel (SCC 20200102, 20300101)	
	[grams/kW-hr] (power output)	[ng/J] (fuel input)	[grams/kW-hr] (power output)	[ng/J] (fuel input)
NO_x [D]	6.92	699	18.8	1,896
CO [D]	267	26,947	4.06	410
SO_x [D]	0.359	36	1.25	126
Particulate [D]	0.439	44	1.34	135
CO_2 [B][c]	661	66,787	704	71,065
Aldehydes [D]	0.30	29	0.28	28
Hydrocarbons				
Exhaust [D]	8.96	905	1.50	152
Evaporative [E]	0.40	41	0.00	0.00
Crankcase [E]	2.95	298	0.03	2.71
Refueling [E]	0.66	66	0.00	0.00

[a]Data based on uncontrolled levels for each fuel from References 1, 3 and 6.
[b]"D" and "E" rated emission factors are most appropriate when applied to a population of industrial engines rather than to an individual power plant, due to the aggregate nature of the emissions data.
[c]Based on assumed 100 percent conversion of carbon in fuel to CO_2 with 87 weight percent carbon in diesel, 86 weight percent carbon in gasoline, average brake-specific fuel consumption of 7,000 Btu/hp-hr, diesel heating value of 19,300 Btu/lb, and gasoline heating value of 20,300 Btu/lb.

Table 3.3.1-3
Speciated Organic Compounds and Air Toxic Emission Factors for Uncontrolled Diesel Engines[a]
(English and Metric Units)

(Source Classification Codes: 20200102, 20300101)

(Emission Factor Rating: E)[b]

Pollutant	[lb/MMBtu] (fuel input)	[ng/J] (fuel input)
Benzene	9.33 E-04	0.401
Toluene	4.09 E-04	0.176
Xylenes	2.85 E-04	0.122
Propylene	2.58 E-03	1.109
1,3 Butadiene[c]	< 3.91 E-05	< 0.017
Formaldehyde	1.18 E-03	0.509
Acetaldehyde	7.67 E-04	0.330
Acrolein	< 9.25 E-05	< 0.040
Polycyclic Aromatic Hydrocarbons (PAH)		
Naphthalene	8.48 E-05	3.64 E-02
Acenaphthylene	< 5.06 E-06	< 2.17 E-03
Acenaphthene	< 1.42 E-06	< 6.11 E-04
Fluorene	2.92 E-05	1.26 E-02
Phenanthrene	2.94 E-05	1.26 E-02
Anthracene	1.87 E-06	8.02 E-04
Fluoranthene	7.61 E-06	3.27 E-03
Pyrene	4.78 E-06	2.06 E-03
Benz(a)anthracene	1.68 E-06	7.21 E-04
Chrysene	3.53 E-07	1.52 E-04
Benzo(b)fluoranthene	< 9.91 E-08	< 4.26 E-05
Benzo(k)fluoranthene	< 1.55 E-07	< 6.67 E-05
Benzo(a)pyrene	< 1.88 E-07	< 8.07 E-05
Indeno(1,2,3-cd)pyrene	< 3.75 E-07	< 1.61 E-04
Dibenz(a,h)anthracene	< 5.83 E-07	< 2.50 E-04
Benzo(g,h,i)perylene	< 4.89 E-07	< 2.10 E-04
Total PAH	1.68 E-04	7.22 E-02

[a]Data are based on the uncontrolled levels of two diesel engines from References 6 and 7.
[b]"E" rated emission factors are due to limited data sets, inherent variability in the population and/or a lack of documentation of test results. "E" rated emission factors may not be suitable for specific facilities or populations and should be used with care.
[c]Data are based on one engine.

Table 3.3.1-4
Diesel Emission Control Technologies[a]

Technology	Affected Parameter[b]	
	Increase	Decrease
Fuel Modifications		
Sulfur Content Increase	PM, Wear	
Aromatic Content Increase	PM, NO_x	
Cetane Number		PM, NO_x
10 percent and 90 percent Boiling Point		PM
Fuel Additives		PM, NO_x
Water/Fuel Emulsions		NO_x
Engine Modifications		
Injection Timing	NO_x, PM, BSFC, Power	NO_x
Fuel Injection Pressure	PM, NO_x	
Injection Rate Control		NO_x, PM
Rapid Spill Nozzles		PM
Electronic Timing & Metering		NO_x, PM
Injector Nozzle Geometry		PM
Combustion Chamber Modifications		NO_x, PM
Turbocharging	PM, Power	NO_x
Charge Cooling		NO_x
Exhaust Gas Recirculation	PM, Power, Wear	NO_x
Oil Consumption Control		PM, Wear
Exhaust After Treatment		
Particulate Traps		PM
Selective Catalytic Reduction		NO_x
Oxidation Catalysts		HC, CO, PM

[a]Reference 4.
[b]NO_x = Nitrogen oxides; PM = Particulate matter; HC = Hydrocarbons; CO = Carbon monoxide; BSFC = Brake specific fuel consumption.

References

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2. Lips, H. I., J. A. Gotterba, and K. J. Lim. *Environmental Assessment of Combustion Modification Controls for Stationary Internal Combustion Engines*, EPA-600/7-81-127, Industrial Environmental Research Laboratory, Office of Environmental Engineering and Technology, Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency, Research Triangle Park, NC, July 1981.

3. *Standards Support and Environmental Impact Statement, Volume I: Stationary Internal Combustion Engines*, EPA-450/2-78-125a, Emission Standards and Engineering Division, Office of Air, Noise, and Radiation, Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency, Research Triangle Park, NC, July 1979.

4. *Technical Feasibility of Reducing NO_x and Particulate Emissions from Heavy-Duty Engines*, Draft Report by Acurex Environmental Corporation for the California Air Resources Board, Sacramento, CA, March 1992, CARB Contract A132-085.

5. *Nonroad Engine and Vehicle Emission Study-Report*, EPA-460/3-91-02, Certification Division, Office of Mobile Sources, Office of Air & Radiation, U.S. Environmental Protection Agency, Research Triangle Park, NC, November 1991.

6. *Pooled Source Emission Test Report: Oil and Gas Production Combustion Sources, Fresno and Ventura Counties, California*, Report prepared by ENSR Consulting and Engineering for Western States Petroleum Association (WSPA), Bakersfield, CA, December 1990, ENSR 7230-007-700.

7. Osborn, W. E., and M. D. McDannel. *Emissions of Air Toxic Species: Test Conducted Under AB2588 for the Western States Petroleum Association*, Report prepared by Carnot for Western States Petroleum Association (WSPA), Glendale, CA, May 1990, CR 72600-2061.

3.3.2 Motor Vehicle Emissions

3.3.2 Motor Vehicle Emissions

Source of Emissions Data

The following information was obtained from:

U.S. Environmental Protection Agency, 1985 and ff. Compilation of Air Pollutant Emission Factors, Volume II: Highway Mobile Sources (Fourth Edition). Section II-7.

Estimating Emissions

General Description. Mobile sources include cars, trucks, and other on-road and off-road vehicles. While each individual vehicle may emit only a small amount of pollution, taken as a whole, their emissions are generally much larger than those from point sources. In fact, transportation accounts for over 50 percent of all air pollution nationwide.

Two groups of motorized vehicles are presented in this section: highway mobile sources and heavy-duty construction equipment. The classes of vehicles within each group are described below in detail.

Highway Mobile Sources. Highway mobile sources are comprised of eight vehicle types:

- Light-duty gasoline-powered vehicles (LDGV)
- Light-duty gasoline-powered trucks I (LDGT1)
- Light-duty gasoline-powered trucks II (LDGT2)
- Heavy-duty gasoline-powered vehicles (HDGV)
- Light-duty diesel-powered vehicles (LDDV)
- Light-duty diesel-powered trucks (LDDT)
- Heavy-duty diesel-powered vehicles (HDDV)
- Motorcycles

Because of their widespread use, LDGVs, or automobiles, are responsible for a large share of air pollutant emissions in many areas of the United States. A LDGV is defined to be any gasoline-fueled vehicle designated primarily for transportation of persons and having a capacity of 12 or less persons.

Light-duty gasoline-powered trucks I (LDGT1) are defined as having a gross vehicle weight rating of 6,000 pounds or less. Although LDGT1s have a load carrying capability that exceeds that of passenger cars, they are often used for personal transportation and light hauling.

Light-duty gasoline-powered trucks II (LDGT2) are defined as having a gross vehicle weight rating between 6,001 and 8,500 pounds. This vehicle type is required since these

trucks were classified as heavy-duty vehicles through the 1978 model year. Beginning with the 1979 model year, these trucks have been considered light-duty trucks.

Heavy-duty gasoline-powered vehicles (HDGV) include any gasoline-fueled motor vehicles designated primarily for the transportation of property and rated at more that 8,500 pounds gross vehicle weight, or designated primarily for transportation of persons and having a capacity of more than 12 persons.

Light-duty diesel-powered vehicles (LDDV) include any diesel-powered automobile designated primarily for transportation of persons and having a capacity of 12 or less persons.

Light-duty diesel-powered trucks (LDDT) include any diesel-powered motor vehicle designed primarily for the transportation of property and rated at 8,500 pounds or less gross vehicle weight.

Heavy-duty diesel-powered vehicles (HDDV) include any diesel-powered motor vehicle designated primarily for the transportation of property and rated at more than 8,500 pounds of gross vehicle weight.

Motorcycles are defined as any motor vehicle designed to travel with no more than three wheels in contact with the ground, and with a curb weight less than 1,500 pounds.

Heavy-Duty Construction Equipment. Heavy-duty construction equipment include:

- Track type tractors
- Track type loaders
- Motor graders
- Wheel tractor scrapers
- Off-highway trucks (includes pavement cold planers and wheel dozers)
- Wheeled loaders
- Wheeled tractors
- Rollers (static and vibratory)
- Miscellaneous machines

The latter category contains an array of less numerous mobile and semi-mobile machines used in construction such as log skidders, hydraulic excavators/crawlers, trenchers, concrete pavers, compact loaders, crane lattice booms, cranes, hydraulic excavator wheels, and bituminous pavers.

The useful life of construction equipment is fairly short because of the frequent and severe usage it must endure. The annual usage of the various categories of equipment considered here ranges from 740 hours (wheeled tractors and rollers) to 2000 hours (scrapers and off-highway trucks). This high level of use results in average vehicle lifetimes of only 6 to 16 years.

Emission Factor Data.

Highway Mobile Sources. Substantial research effort has been expended to accurately characterize emissions from these vehicles. EPA's ongoing program to collect in-use vehicle emissions data was instituted a number of years ago in order to estimate their emission levels.
In addition to the methodologies presented for calculating the basic exhaust emission levels for HC, CO, and NOx, data are referenced in *AP-42* for crankcase emissions, evaporative hydrocarbon emissions from vehicles that are parked, from vehicles that are in operation, and from vehicles that are being refueled, and emissions in the idle mode. Information is also given regarding the emission correction factors and travel weighting fractions.

The emission factor estimation procedures are not reproduced in this desk reference because they are very detailed. These procedures are incorporated into the MOBILE 5a program that is described in the *Emissions Model* section below. It is recommended that the user of this guide use the MOBILE 5a software program to estimate pollutant emissions. Please refer to the user's manual (provided on disk with the MOBILE 5a program in Appendix D) for detailed instructions on how to use this program.

Heavy-Duty Construction Equipment. The Environmental Research and Technology, Inc. prepared a report[3] under the sponsorship of a consortium of industry groups. This report, referred to as the CAL/ERT report, provided a very comprehensive investigation of farm construction and industrial equipment emissions. The emissions of twenty different types of construction equipment are grouped roughly according to the categories in the Third Edition by their populations in California (based on a report prepared by the California Air Resources Board[4]). The updated emission factors on HC/CO/NO_x for heavy-duty construction equipment for diesel engines are reported in Table 3.3.2-1. No update has been done on other emissions (aldehydes, sulfur oxides, and particulates), and their values are carried over from the Third Edition. Less than five percent of the sales use gasoline engines, and the trend is toward complete dieselization. No update has been done on the gasoline engine construction equipment emissions. Therefore, the emission factors for gasoline engines from the Third Edition are reprinted in Table 3.3.2-2. The factors are reported in three different forms: on the basis of running time, fuel consumed, and power consumed.

In order to estimate emissions from time-based emission factors, annual equipment usage in hours must be estimated. The following estimates of use for the equipment listed in the tables should permit reasonable emission calculations.

Table 3.3.2-1
Emission Factors for Heavy-Duty Diesel-Powered Construction Equipment[a]

(Emission Factor Rating: C)

Pollutant	Track-Type Tractor	Wheeled Tractor	Wheeled Dozer[b]	Scraper	Motor Grader	Wheeled Loader	Track-Type Loader	Highway Truck	Roller	Miscellaneous
Carbon Monoxide										
g/hr	157.01	1622.77		568.19	68.46	259.58	91.15	816.81	137.97	306.37
lb/hr	0.346	3.59		1.257	0.151	0.572	0.201	1.794	0.304	0.675
g/kWh	2.88	9.84		3.28	2.06	3.63	3.03	4.70	8.08	6.16
g/hphr	2.15	7.34		2.45	1.54	2.71	2.26	2.28	6.03	4.60
kg/10^3 liter	9.4	32.19		10.16	6.55	11.79	9.93	14.73	22.64	18.41
lb/10^3 gal	78.5	268.5		84.6	54.65	98.66	82.85	123.46	188.37	153.51
Exhaust Hydrocarbons										
g/hr	55.06	85.26		128.15	18.07	113.17	44.55	86.84	30.58	69.35
lb/hr	0.121	0.188		0.282	0.040	0.25	0.098	0.192	0.067	0.152
g/kWh	1.01	2.36		0.74	0.48	1.59	1.49	0.50	1.30	1.35
g/hphr	0.75	1.76		0.55	0.36	0.97	1.11	0.37	0.97	1.01
kg/10^3 liter	3.31	7.74		2.28	1.53	5.17	4.85	1.58	3.60	4.04
lb/10^3 gal	27.6	64.6		19.0	12.73	43.16	40.55	13.16	30.09	33.70
Nitrogen Oxides (NOx as NO2)										
g/hr	570.70	575.84		1740.74	324.43	858.19	375.22	1889.16	392.90	767.30
lb/hr	1.26	1.269		3.840	0.713	1.89	0.827	4.166	0.862	1.691
g/kWh	10.47	15.96		10.00	9.57	11.81	12.46	10.92	17.49	14.75
g/hphr	7.81	11.91		7.46	7.14	8.81	9.30	8.15	13.05	11.01
kg/10^3 liter	34.16	52.35		30.99	30.41	38.5	40.78	34.29	48.49	44.10
lb/10^3 gal	284.92	436.67		258.6	253.84	321.23	339.82	286.10	404.51	368.01
Aldehydes (RCHO as HCHO)										
g/hr	12.4	13.5	29.5	65.	5.54	18.8	4.00	51.0	7.43	13.9
lb/hr	0.027	0.030	0.065	0.143	0.012	0.041	0.009	0.112	0.016	0.031
g/kWh	0.228	0.378	0.215	0.375	0.162	0.264	0.134	0.295	0.263	0.272
g/hphr	0.170	0.282	0.160	0.280	0.121	0.197	0.100	0.220	0.196	0.203
kg/10^3 liter	0.745	1.23	0.690	1.16	0.517	0.859	0.439	0.928	0.731	0.813
lb/10^3 gal	6.22	10.3	5.76	9.69	4.31	7.17	3.66	7.74	6.10	6.78

Table 3.3.2-1
Emission Factors for Heavy-Duty Diesel-Powered Construction Equipment[a]

(Emission Factor Rating: C)

Pollutant	Track-Type Tractor	Wheeled Tractor	Wheeled Dozer[b]	Scraper	Motor Grader	Wheeled Loader	Track-Type Loader	Highway Truck	Roller	Miscellaneous
Sulfur Oxides (SOx as SO2)										
g/hr	62.3	40.9	158.	210.	39.0	82.5	34.4	206.	30.5	64.7
lb/hr	0.137	0.090	0.348	0.463	0.086	0.182	0.076	0.454	0.067	0.143
g/kWh	1.14	1.14	1.16	1.21	1.17	1.15	1.14	1.19	1.34	1.25
g/hphr	0.851	0.851	0.867	0.901	0.874	0.857	0.853	0.887	1.00	0.932
$kg/10^3$ liter	3.73	3.73	3.74	3.74	3.73	3.74	3.74	3.74	3.73	3.73
$lb/10^3$ gal	31.1	31.1	31.2	31.2	31.1	31.2	31.2	31.2	31.1	31.1
Particulate										
g/hr	50.7	61.5	75.	184.	27.7	77.9	26.4	116.	22.7	63.2
lb/hr	0.112	0.136	0.165	0.406	0.061	0.172	0.058	0.256	0.050	0.139
g/kWh	0.928	1.70	0.551	1.06	0.838	1.08	0.878	0.673	1.04	1.21
g/hphr	0.692	1.27	0.411	0.789	0.625	0.805	0.655	0.502	0.778	0.902
$kg/10^3$ liter	3.03	5.57	1.77	3.27	2.66	3.51	2.88	2.12	2.90	3.61
$lb/10^3$ gal	25.3	46.5	14.8	27.3	22.2	29.3	24.0	17.7	24.2	30.1

[a] References 3 and 4 for the HC, CO, and NOx emissions, and References 1 and 2 for the other pollutants.
[b] The wheeled dozer HC, CO, and NOx emissions are included in the off-highway truck category.

Table 3.3.2-2
Emission Factors for Heavy-Duty Gasoline-Powered Construction Equipment[a]

(Emission Factor Rating: C)

Pollutant	Wheeled Tractor	Motor Grader	Wheeled Loader	Roller	Miscellaneous
Carbon Monoxide					
g/hr	4320.	5490.	7060.	6080.	7720.
lb/hr	9.52	12.1	15.6	13.4	17.0
g/kWh	190.	251.	219.	271.	266.
g/hphr	142.	187.	163.	202.	198.
kg/10^3 liter	389.	469.	435.	460.	475.
lb/10^3 gal	3250.	3910.	3630.	3840.	3960.
Exhaust Hydrocarbons					
g/hr	164.	186.	241.	277.	254.
lb/hr	0.362	0.410	0.531	0.611	0.560
g/kWh	7.16	8.48	7.46	12.40	8.70
g/hphr	5.34	6.32	5.56	9.25	6.49
kg/10^3 liter	14.6	15.8	14.9	21.1	15.6
lb/10^3 gal	122.	132.	124.	176.	130.
Evaporative Hydrocarbons[b]					
g/hr	30.9	30.0	29.7	28.2	25.4
lb/hr	0.0681	0.0661	0.0655	0.0622	0.0560
Crankcase Hydrocarbons[b]					
g/hr	32.6	37.1	48.2	55.5	50.7
lb/hr	0.0719	0.0818	0.106	0.122	0.112
Nitrogen Oxides (NOx as NO2)					
g/hr	195.	145.	235.	164.	187.
lb/hr	0.430	0.320	0.518	0.362	0.412
g/kWh	8.54	6.57	7.27	7.08	6.48
g/hphr	6.37	4.90	5.42	5.28	4.79
kg/10^3 liter	17.5	12.2	14.5	12.0	11.5
lb/10^3 gal	146.	102.	121.	100.	95.8
Aldehydes (RCHO as HCHO)					
g/hr	7.97	8.80	9.65	7.57	9.00
lb/hr	0.0176	0.0194	0.0213	0.0167	0.0198
g/kWh	0.341	0.386	0.298	0.343	0.298
g/hphr	0.254	0.288	0.222	0.256	0.222
kg/10^3 liter	0.697	0.721	0.593	0.582	0.532
lb/10^3 gal	5.82	6.02	4.95	4.86	4.44

Table 3.3.2-2
Emission Factors for Heavy-Duty Gasoline-Powered Construction Equipment[a]

(Emission Factor Rating: C)

Pollutant	Wheeled Tractor	Motor Grader	Wheeled Loader	Roller	Miscellaneous
Sulfur Oxides (SOx as SO2)					
g/hr	7.03	7.59	10.6	8.38	10.6
lb/hr	0.0155	0.0167	0.0234	0.0185	0.0234
g/kWh	0.304	0.341	0.319	0.373	0.354
g/hphr	0.227	0.254	0.238	0.278	0.264
$kg/10^3$ liter	0.623	0.636	0.636	0.633	0.633
$lb/10^3$ gal	5.20	5.31	5.31	5.28	5.28
Particulate					
g/hr	10.9	9.40	13.5	11.8	11.7
lb/hr	0.0240	0.0207	0.0298	0.0260	0.0258
g/kWh	0.484	0.440	0.421	0.527	0.406
g/hphr	0.361	0.328	0.314	0.393	0.303
$kg/10^3$ liter	0.991	0.822	0.839	0.895	0.726
$lb/10^3$ gal	8.27	6.86	7.00	7.47	6.06

[a] References 1 and 2.
[b] Evaporative and crankcase hydrocarbons based on operating time only (Reference 1).

Category	Annual Operation, hours/year
Tracklaying tractors	1050
Tracklaying shovel loaders	1100
Motor graders	830
Scrapers	2000
Off-highway trucks	4000
(including wheeled dozers)	2000
Wheeled loaders	1140
Wheeled tractors	740
Rollers	740
Miscellaneous	1000

The best method for calculating emissions, however, is on the basis of "brake specific" emission factors (g/kWh or g/hphr). Emissions are calculated by taking the product of the brake specific emission factor, the usage in hours, the power available (that is, rated power), and the load factor (the power actually used divided by the power available). The rated power and load factor data for vehicles are available from equipment manufacturers or vendors.

Emissions Model. The EPA's Office of Mobile Sources (OMS) developed a computer program, MOBILE 5a, that estimates hydrocarbon (HC), carbon monoxide (CO), and oxides of nitrogen (NOx) emission factors for gasoline-fueled and diesel highway motor vehicles. The program uses the calculation procedures presented in *AP-42*.

MOBILE 5a calculates emission factors for the eight highway mobile source types described above. The emission factor estimates depend on various conditions such as ambient temperatures, average travel speed, operating modes, fuel volatility, and mileage accrual rates. Many of the variables affecting vehicle emissions can be specified by the user. MOBILE 5a will estimate emission factors for any calendar year between 1960 and 2020, inclusive. The 25 most recent model years are considered to be in operation in each calendar year. MOBILE 5a does not calculate emission factors for heavy-duty construction equipment.

Mitigation Techniques

Mitigation requirements are dependent on the location of the project, the size of the area where vehicle emissions are likely to increase, and the duration of the increased emissions. If the project is located in an area currently attaining the state and federal ambient air quality standards, the vehicle emissions from the project are limited in area and short in duration, then no violations of the standards may be expected. No mitigation measures may be required. If, however, the project is located in a nonattainment area, the project area is large, or the impact occurs over a long period of time, then the project may have a significant impact on local air quality. During the construction phase of

many projects, required mitigation techniques may include installing and regularly maintaining emission control devices on all vehicles, and shutting down motorized equipment when not in use. Measures used to mitigate air quality impacts from transportation projects are usually implemented on a regional basis by local or state regulatory agencies. These measures focus on ways to reduce vehicle miles traveled and improve traffic flow (increase speeds).

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3.3.3 Large Diesel Engines

3.3.3 Large Diesel Engines

Source of Emissions Data

The following information was obtained from:

U.S. Environmental Protection Agency. 1985 and ff. *Compilation of Air Pollutant Emission Factors, Volume I: Stationary Point and Area Sources* (Fourth Edition). Section 3.4.

Estimating Emissions

General Description. The primary domestic use of large stationary diesel engines (greater than 600 hp) is in oil and gas exploration and production. These engines, in groups of three to five, supply mechanical power to operate drilling (rotary table), mud pumping, and hoisting equipment, and may also operate pumps or auxiliary power generators. Another frequent application of large stationary diesels is electricity generation for both base and standby service. Smaller uses include irrigation, hoisting, and nuclear power plant emergency cooling water pump operation.

Dual fuel engines were developed to obtain compression ignition performance and the economy of natural gas, using a minimum of 5 to 6 percent diesel fuel to ignite the natural gas. Large dual fuel engines have been used almost exclusively for prime electric power generation. This section includes all dual fuel engines.

All reciprocating internal combustion (IC) engines operate by the same basic process. A combustible mixture is first compressed in a small volume between the head of a piston and its surrounding cylinder. The mixture is then ignited, and the resulting high-pressure products of combustion push the piston through the cylinder. This movement is converted from linear to rotary motion by a crankshaft. The piston returns, pushing out exhaust gases, and the cycle is repeated.

There are two methods used for stationary reciprocating IC engines: compression ignition (CI) and spark ignition (SI). This section deals only with compression ignition engines.

In compression ignition engines, combustion air is first compression-heated in the cylinder, and diesel fuel oil is then injected into the hot air. Ignition is spontaneous as the air is above the auto-ignition temperature of the fuel. Spark ignition engines initiate combustion by the spark of an electrical discharge. Usually the fuel is mixed with the air in a carburetor (for gasoline) or at the intake valve (for natural gas), but occasionally the fuel is injected into the compressed air in the cylinder. Although all diesel-fueled engines are compression ignited and all gasoline and gas-fueled engines are spark ignited, gas can be used in a compression ignition engine if a small amount of diesel fuel is injected into the compressed gas/air mixture to burn any mixture ratio of gas and diesel oil (hence the name dual fuel), from 6 to 100 percent diesel oil.

CI engines usually operate at a higher compression ratio (ratio of cylinder volume when the piston is at the bottom of its stroke to the volume when it is at the top) than SI engines because fuel is not present during compression; hence there is no danger of premature auto-ignition. Since engine thermal efficiency rises with increasing pressure ratio (and pressure ratio varies directly with compression ratio), CI engines are more efficient than SI engines. This increased efficiency is gained at the expense of poorer response to load changes and a heavier structure to withstand the higher pressures.

Emission Factor Data. Most of the pollutants from IC engines are emitted through the exhaust. However, some hydrocarbons escape from the crankcase as a result of blowby (that is, gases vented from the oil pan after they have escaped from the cylinder past the piston rings) and from the fuel tank and carburetor because of evaporation. Nearly all of the hydrocarbons from diesel CI engines enter the atmosphere from the exhaust. Crankcase blowby is minor because hydrocarbons are not present during compression of the charge. Evaporative losses are insignificant in diesel engines due to the low volatility of diesel fuels. In general, evaporative losses are also negligible in engines using gaseous fuels because these engines receive their fuel continuously from a pipe rather than via a fuel storage tank and fuel pump.

The primary pollutants from internal combustion engines are NO_x, organic compounds (hydrocarbons), CO, and particulate matter, which include both visible (smoke) and nonvisible emissions. The other pollutants are primarily the result of incomplete combustion. Ash and metallic additives in the fuel also contribute to the particulate content of the exhaust. SO_x also appears in the exhaust from IC engines.

The primary pollutant of concern from large stationary diesel and all stationary dual fuel engines is NO_x, which readily forms in the high temperature, pressure, nitrogen content of the fuel, and excess air environment found in these engines. Lesser amounts of CO and organic compounds are emitted. The sulfur compounds, mainly SO_2, are directly related to the sulfur content of the fuel. SO_x emissions will usually be quite low because of the negligible sulfur content of diesel fuels and natural gas.

Tables 3.3.3-1 (English units) and 3.3.3-2 (metric units) contain gaseous emission factors. Table 3.3.3-3 shows the particulate and particle sizing emission factors.

Emission Calculations. Pollutant emissions from large diesel engines can be calculated using the methodology described in Section 3.3.1, "Gasoline and Diesel Industrial Engines." The method calculates emissions on the basis of "brake-specific" emission factors (g/hp-hr or g/kW-hr). Emissions are calculated by taking the product of the brake-specific emission factor, the usage in hours (that is, hours per year or hours per day), the power available (rated power), and the load factor (the power actually used divided by the power available). The equation is as follows:

$$E = EF \cdot U \cdot P \cdot L \cdot \left(\frac{1\ lb}{454\ grams}\right)$$

where E = Daily pollutant emissions, lbs per day
EF = Emission factor, grams per hp-hr (grams per kW-hr)
U = Usage, hours per day
P = Power available, horsepower (kilowatts)
L = Load factor, dimensionless

Example

A large stationary diesel engine (1,000 hp) is to be used for mechanical power generation to operate drilling equipment in an oil exploration project. Estimate the NO_X emissions assuming the engine will run 12 hours per day and has a rated capacity of 0.85.

$$E = \left(11\frac{grams}{hp \cdot hour}\right) \cdot \left(12\frac{hours}{day}\right) \cdot (1{,}000\ hp) \cdot (0.85) \cdot \left(\frac{1\ lb}{454\ grams}\right)$$

$$= 247\frac{lb}{day}\ of\ NO_x$$

An alternative method of estimating emissions is to take the product of the emission factor based on fuel input (lb/MMBtu or ng/J) and the fuel usage.

Hazardous Air Pollutants. Table 3.3.3-4 shows the speciated organic compound emission factors and Table 3.3.3-5 shows the emission factors for PAHs. These tables do not provide a complete speciated organic compound and PAH listing since they are based only on a single engine test. They are to be used for rough order-of-magnitude comparisons. Emissions can be estimated using the same procedure outlined above.

Mitigation Techniques

Control measures to date have been directed mainly at limiting NO_X emissions because NO_X is the primary pollutant from diesel and dual fuel engines. Table 3.3.3-6 shows the NO_X reduction and fuel consumption penalties for diesel and dual fueled engines based on some of the available control techniques. All of these controls are engine control techniques except for the selective catalytic reduction (SCR) technique, which is a post-combustion control. The emission reductions shown are those which have been demonstrated. The effectiveness

of controls on a particular engine will depend on the specific design of each engine, and the effectiveness of each technique could vary considerably. Other NO_x control techniques exist but are not included in Table 3.4-6. These techniques include internal/external exhaust gas recirculation (EGR), combustion chamber modification, manifold air cooling, and turbocharging.

Table 3.3.3-1
Gaseous Emission Factors for Large Stationary Diesel and all Stationary Dual Fuel Engines[a]
(English Units)
(Source Classification Codes)

Pollutant	Diesel Fuel (SCC 20200401)			Dual Fuel[b] (SCC 20200402)		
	[grams/hp-hr] (power output)	[lb/MMBtu] (fuel input)	Emission Factor Rating[c]	[grams/hp-hr] (power output)	[lb/MMBtu] (fuel input)	Emission Factor Rating[c]
NO_x	11	3.1	C	9.2	3.1	D
CO	2.4	0.81	C	2.3	0.79	D
SO_x[d]	$3.67S_1$	$1.01S_1$	B	$0.184S_1 + 4.34S_2$	$0.05S_1 + 0.895S_2$	B
CO_2[e]	524	165	B	350	110	B
TOC,[f] (as CH_4)	0.32	0.09	C	2.4	0.8	D
Methane	0.03	0.01	E[g]	1.8	0.6	E[h]
Nonmethane	0.33	0.10	E[g]	0.6	0.2	E[h]

[a]Data are based on uncontrolled levels for each fuel from references 4, 5, and 6. When necessary, the average heating value of diesel was assumed to be 19,300 Btu/lb with a density of 7.1 lb/gal. The power output and fuel input values were averaged independently from each other due to the use of actual Brake-Specific Fuel Consumption values for each data point and the use of data that may have enough information to calculate only one of the two emission factors (e.g., if there was enough information to calculate lb/MMBtu, but not enough to calculate the g/hp-hr). The emission factors are based on averages across all manufacturers and duty cycles. The actual emissions from a particular engine or manufacturer could vary considerably from these levels.

[b]Dual fuel is based on a mixture of 95 percent natural gas and 5 percent diesel fuel.

[c]"D" and "E" rating for emission factors are due to limited data sets, inherent variability in the population and/or a lack of documentation of test results. "D" and "E" rated emission factors may not be suitable for specific facilities or populations and should be used with care.

[d]Emission factors are based on the assumption that all sulfur in the fuel is converted to SO_2. S_1 = percent sulfur in diesel fuel; S_2 = percent sulfur in gas.

[e]Based on assumed 100 percent conversion of carbon in fuel to CO_2 with 87 weight percent carbon in diesel, 70 weight percent carbon in natural gas, dual fuel mixture of 5 percent diesel with 95 percent natural gas, average brake specific fuel consumption of 7,000 Btu/hp-hr, diesel heating value of 19,300 Btu/lb, and natural gas heating value of 23,900 Btu/lb.

[f]Total organic compounds.

[g]Based on emissions data from one engine.

[h]Based on the assumption that nonmethane organic compounds are 25 percent of TOC emissions from dual fuel engines. Molecular weight of nonmethane gas stream is assumed to be that of methane.

Table 3.3.3-2
Gaseous Emission Factors for Large Stationary Diesel and all Stationary Dual Fuel Engines[a]
(Metric Units)
(Source Classification Codes)

Pollutant	Diesel Fuel (SCC 20200401)			Dual Fuel[b] (SCC 20200402)		
	[g/kW-hr] (power output)	[ng/J] (fuel input)	Emission Factor Rating[c]	[g/kW-hr] (power output)	[ng/J] (fuel input)	Emission Factor Rating[c]
NO_x	14	1,322	C	12.3	1,331	D
CO	3.2	349	C	3.1	340	D
SO_x[d]	$4.92S_1$	$434S_1$	B	$0.25S_1 + 4.34S_2$	$21.7S_1 + 384S_2$	B
CO_2[e]	703	70,942	B	469	47,424	B
TOC,[f] (as CH_4)	0.43	38	C	3.2	352	D
Methane	0.04	4	E[g]	2.4	240	E[h]
Nonmethane	0.44	45	E[g]	0.8	80	E[h]

[a]Data are based on uncontrolled levels for each fuel from references 4, 5, and 6. When necessary, the average heating value of diesel was assumed to be 19,300 Btu/lb with a density of 7.1 lb/gal. The power output and fuel input values were averaged independently from each other due to the use of actual Brake-Specific Fuel Consumption values for each data point and the use of data that may have enough information to calculate only one of the two emission factors (e.g., if there was enough information to calculate lb/MMBtu, but not enough to calculate the g/hp-hr). The emission factors are based on averages across all manufacturers and duty cycles. The actual emissions from a particular engine or manufacturer could vary considerably from these levels.

[b]Dual fuel is based on 95 percent natural gas and 5 percent diesel fuel.

[c]"D" and "E" rating for emission factors are due to limited data sets, inherent variability in the population and/or a lack of documentation of test results. "D" and "E" rated emission factors may not be suitable for specific facilities or populations and should be used with care.

[d]Emission factors are based on the assumption that all sulfur in the fuel is converted to SO_2. S_1=percent sulfur in fuel oil; S_2=percent sulfur in gas.

[e]Based on assumed 100 percent conversion of carbon in fuel to CO_2 with 87 weight percent carbon in diesel, 70 weight percent carbon in natural gas, dual fuel mixture of 5 percent diesel with 95 percent natural gas, average brake specific fuel consumption of 7,000 Btu/hp-hr, diesel heating value of 19,300 Btu/lb, and natural gas heating value of 23,900 Btu/lb.

[f]Total organic compounds.

[g]Based on emissions data from one engine.

[h]Based on the assumption that nonmethane organic compounds are 25 percent of TOC emissions from dual fuel engines. Molecular weight of nonmethane gas stream is assumed to be that of methane.

Table 3.3.3-3
Particulate and Particle Sizing Emission Factors for Large Stationary Diesel Engines[a]
(English and Metric Units)

(Source Classification Code: 20200401)

(Emission Factor Rating: E)[b]

Pollutant	Power Output		Fuel Input	
	[grams/hp-hr]	[grams/kW-hr]	[lb/MMBtu]	[ng/J]
Particulate Size Distribution				
<1 μm	0.1520	0.2038	0.0478	20.56
1-3 μm	0.0004	0.0005	0.0001	0.05
3-10 μm	0.0054	0.0072	0.0017	0.73
>10 μm	0.0394	0.0528	0.0124	5.33
Total PM_{10} (≤10 μm)	0.1578	0.2116	0.0496	21.34
TOTAL	0.1972	0.2644	0.0620	26.67
Particulate Emissions				
Solids	0.2181	0.2925	0.0686	29.49
Condensables	0.0245	0.0329	0.0077	3.31
TOTAL	0.2426	0.3253	0.0763	32.81

[a]Data are based on the uncontrolled levels of one diesel engine from reference 6. The data for the particulate emissions were collected using Method 5 and the particle size distributions were collected using a Source Assessment Sampling System (SASS).
[b]"E" rating for emission factors is due to limited data sets, inherent variability in the population and/or a lack of documentation of test results. "E" rated emission factors may not be suitable for specific facilities or populations and should be used with care.

Table 3.3.3-4
Speciated Organic Compound Emission Factors for Large Stationary Diesel Engines[a]
(English and Metric Units)

(Source Classification Code: 20200401)

(Emission Factor Rating: E)[b]

Pollutant	[lb/MMBtu] (fuel input)	[ng/J] (fuel input)
Benzene	7.76 E-04	3.34 E-01
Toluene	2.81 E-04	1.21 E-01
Xylenes	1.93 E-04	8.30 E-02
Propylene	2.79 E-03	1.20 E-00
Formaldehyde	7.89 E-05	3.39 E-02
Acetaldehyde	2.52 E-05	1.08 E-02
Acrolein	7.88 E-06	3.39 E-03

[a]Data based on the uncontrolled levels of one diesel engine from reference 5. There was enough information to compute the input-specific emission factors of lb/MMBtu, but not enough to calculate the output-specific emission factor of g/hp-hr. There was enough information to compute the input-specific emission factors of ng/J, but not enough to calculate the output-specific emission factor of g/kW-hr.
[b]"E" rating for emission factors are due to limited data sets, inherent variability in the population and/or a lack of documentation of test results. "E" rated emission factors may not be suitable for specific facilities or populations and should be used with care.

Table 3.3.3-5
PAH Emission Factors for Large Stationary Diesel Engines[a]
(English and Metric Units)
(Source Classification Code: 20200401)

(Emission Factor Rating: E)[b]

Pollutant	[lb/MMBtu] (fuel input)	[ng/J] (fuel input)
PAHs		
Naphthalene	1.30 E-04	5.59 E-02
Acenaphthylene	9.23 E-06	3.97 E-03
Acenaphthene	4.68 E-06	2.01 E-03
Fluorene	1.28 E-05	5.50 E-03
Phenanthrene	4.08 E-05	1.75 E-02
Anthracene	1.23 E-06	5.29 E-04
Fluoranthene	4.03 E-06	1.73 E-03
Pyrene	3.71 E-06	1.60 E-03
Benz(a)anthracene	6.22 E-07	2.67 E-04
Chrysene	1.53 E-06	6.58 E-04
Benzo(b)fluoranthene	1.11 E-06	4.77 E-04
Benzo(k)fluoranthene	< 2.18 E-07	< 9.37 E-05
Benzo(a)pyrene	< 2.57 E-07	< 1.10 E-04
Indeno(1,2,3-cd)pyrene	< 4.14 E-07	< 1.78 E-04
Dibenz(a,h)anthracene	< 3.46 E-07	< 1.49 E-04
Benzo(g,h,l)perylene	< 5.56 E-07	< 2.39 E-04
Total PAH	2.12 E-04	9.09 E-02

[a]Data are based on the uncontrolled levels of one diesel engine from reference 5. There was enough information to compute the input-specific emission factors of lb/MMBtu and ng/J but not enough to calculate the output-specific emission factor of g/hp-hr and g/kW-hr.
[b]"E" rating for emission factors is due to limited data sets, inherent variability in the population and/or a lack of documentation of test results. "E" rated emission factors may not be suitable for specific facilities or populations and should be used with care.

Table 3.3.3-6
NO_x Reduction and Fuel Consumption Penalties for Large Stationary Diesel and Dual Fuel Engines[a]

(Source Classification Codes)

Control Approach		Diesel (SCC 20200401)		Dual Fuel (SCC 20200402)	
		Percent NO_x Reduction	ΔBSFC,[b] Percent	Percent NO_x Reduction	ΔBSFC,[b] Percent
Derate	10%			<20	4
	20%	<20	4		
	25%	5-23	1-5	1-33	1-7
Retard	2°	<20	4	<20	3
	4°	<40	4	<40	1
	8°	28-45	2-8	50-73	3-5
Air-to-Fuel	3%			<20	0
	±10%	7-8	3	25-40	1-3
Water Injection (H_2O/fuel ratio)	50%	25-35	2-4		
Selective Catalytic Reduction (SCR)		80-95	0	80-95	0

[a]Data are based on references 1, 2, and 3. The reductions shown are typical and will vary depending on the engine and duty cycle.
[b]BSFC = Brake-Specific Fuel Consumption.

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3.4.1 Asphalt Paving

3.4.1 Asphalt Paving

Source of Emissions Data

The following information was obtained from:

U.S. Environmental Protection Agency. 1985 and ff. *Compilation of Air Pollutant Emission Factors, Volume I: Stationary Point and Area Sources* (Fourth Edition). Section 4.5.

Estimating Emissions

General Description.[1-3] Asphalt surfaces and pavements are composed of compacted aggregate and an asphalt binder. Aggregate materials are produced from rock quarries as manufactured stone or are obtained from natural gravel or soil deposits. Metal ore refining processes produce artificial aggregates as a by-product. In asphalt, the aggregate performs three functions. It transmits the load from the surface to the base course, takes the abrasive wear of traffic, and provides a nonskid surface. The asphalt binder holds the aggregate together, preventing displacement and loss of aggregate and providing a waterproof cover for the base.

Asphalt binders take the form of asphalt cement (the residue of the distillation of crude oils) and liquified asphalts. To be used for pavement, asphalt cement, which is semisolid, must be heated prior to mixing with aggregate. The resulting hot mix asphalt concrete is generally applied in thicknesses of from 2 to 6 inches. Liquified asphalts are (1) asphalt cutbacks (asphalt cement thinned or "cut back" with volatile petroleum distillates such as naptha, kerosene, etc.) and (2) asphalt emulsions (nonflammable liquids produced by combining asphalt and water with an emulsifying agent, such as soap). Liquified asphalts are used in tack and seal operations, in priming roadbeds for hot mix application, and for paving operations up to several inches thick.

Cutback asphalts fall into three broad categories: rapid cure (RC), medium cure (MC), and slow cure (SC) road oils. SC, MC, and RC cutbacks are prepared by blending asphalt cement with heavy residual oils, kerosene-type solvents, or naptha and gasoline solvents, respectively. Depending on the viscosity desired, the proportions of solvent added generally range from 25 to 45 percent by volume.

Emulsified asphalts are of two basic types. One type relies on water evaporation to cure. The other type (cationic emulsions) relies on ionic bonding of the emulsion and the aggregate surface. Emulsified asphalt can substitute for cutback in almost any application. Emulsified asphalts are gaining in popularity, because of the energy and environmental problems associated with the use of cutback asphalts.

Emission Factor Data.[1,2] The primary pollutants of concern from asphalts and asphalt paving operations are VOCs. Of the three types of asphalts, the major source of VOCs is cutback. Only minor amounts of VOCs are emitted from emulsified asphalts and asphalt cement.

VOC emissions from cutback asphalts result from the evaporation of the petroleum distillate solvent, or diluent, used to liquify the asphalt cement. Emissions occur at both the job site and the mixing plant. At the job site, VOCs are emitted from the equipment used to apply the asphaltic product and from the road surface. At the mixing plant, VOCs are released during mixing and stockpiling. The largest source of emissions, however, is the road surface itself.

For any given amount of cutback asphalt, total emissions are believed to be the same, regardless of stockpiling, mixing and application times. The two major variables affecting both the quantity of VOC emitted and the time over which emissions occur are the type and the quantity of petroleum distillate used as a diluent. As an approximation, long-term emissions from cutback asphalts can be estimated by assuming that 95 percent of the diluent evaporates from RC cutback asphalts, 70 percent from MC cutbacks, and about 25 percent from SC asphalts, by weight percent. Some of the diluent appears to be retained permanently in the road surface after application. Limited test data suggest that from RC asphalt, 75 percent of the total diluent loss occurs on the first day after application, 90 percent occurs within the first month, and 95 percent in 3 to 4 months. Evaporation takes place more slowly from MC asphalts, with roughly 20 percent of the diluent being emitted during the first day, 50 percent during the first week, and 70 percent after 3 to 4 months. No measured data are available for SC asphalts, although the quantity emitted is believed to be considerably less than with either rapid or medium cure asphalts, and the time during which emissions take place is expected to be considerably longer (Figure 3.4.1-1).

Emission Calculations. To determine VOC emissions, the volume of diluent present in the cutback asphalt must be determined. First, the relationship between the volume of diluent and the volume of asphalt cement is

$$X = V_d * (X + Y) \quad (1)$$

where X = Volume of diluent (liter)
V_d = Volume percent of diluent present in the asphalt cement (%)
Y = Volume of asphalt cement (liter)

The weight of the cutback asphalt is a function of the volume of diluent and the volume of asphalt cement and is expressed as

$$W = X \cdot \rho_d + Y \cdot \rho_{ac} \quad (2)$$

where W = Weight of the cutback asphalt (kilograms)
ρ_d = Density of the diluent present in the diluent (kilograms/liter)
ρ_{ac} = Density of the asphalt cement (kilograms/liter)

Combining Equations (1) and (2) and solving for the volume of diluent results in the following equation:

$$X = \frac{W}{\left(\rho_d + \rho_{ac} \cdot \left(\frac{100 - V_d}{V_d}\right)\right)} \quad (3)$$

An example calculation for determining VOC emissions from cutback asphalts is given below.

Example

Local records indicate that 10,000 kg of RC cutback asphalt (containing 45 percent diluent, by volume) is expected to be applied in a new campground. Calculate the mass of VOC emitted 1 year after the application of cutback asphalt. Assume the density of the diluent, naptha (coal-tar), is 0.7 kg/liters and the density of asphalt cement is 1.1 kg/liters. Substituting these values into Equation (3) results in the following:

$$X = 10{,}000 \frac{kg}{\left(0.7 \frac{kg}{liters} + 1.1 \frac{kg}{liters} \cdot \left(\frac{100 - 45}{45}\right)\right)} \quad (4)$$

$$= 4{,}900 \ liters = 3{,}400 \ kg$$

Assuming that 95 percent of this is evaporative VOC, the total emissions evaporated 1 year after application are: 3,400 kg x 0.95 = 3,200 kg (i.e., 32%, by weight, of the cutback asphalt eventually evaporates).

These equations can be used for medium cure and slow cure asphalts by assuming typical diluent densities of 0.8 and 0.9 kg/liter, respectively. Of course, if actual density values are known from local records, they should be used in the above equations rather than typical values. Also, if different diluent contents are used, they should also be reflected in the above calculations. If actual diluent contents are not known, a typical value of 35 percent may be assumed for inventory purposes.

In lieu of solving the equations in the above example, Table 3.4.1-1 may be used to estimate long-term emissions from cutback asphalts. Table 3.4.1-1 directly yields long-term emissions as a function of the volume of diluent added to the cutback and of the density of the diluents and asphalt cement used in the cutback asphalt. If short-term emissions are to be estimated, Figure 3.4.1-1 should be used in conjunction with Table 3.4.1-1.

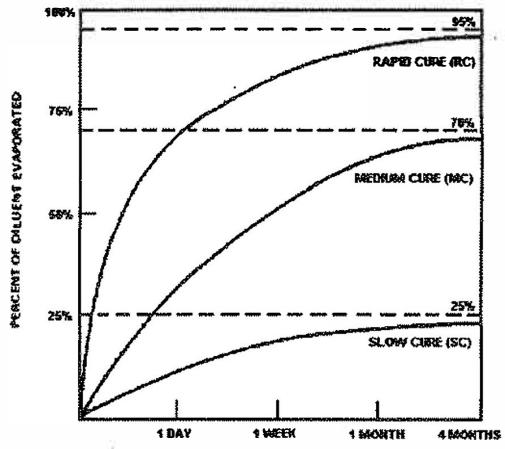

Figure 3.4.1-1. Percent of diluent evaporated from cutback asphalt over time.

Table 3.4.1-1
Evaporative VOC Emissions from Cutback Asphalts as a Function of Diluent Content and Cutback Asphalt Type[a]

Emission Factor Rating: C

Type of Cutback[b]	Percent, by Volume, of Diluent in Cutback[c]		
	25%	35%	45%
Rapid cure	17	24	32
Medium cure	14	20	26
Slow cure	5	8	10

[a]These numbers represent the percent, by weight, of cutback asphalt evaporated. Factors are based on References 1 and 2.
[b]Typical densities assumed for diluents used in RC, MC, and SC cutbacks are 0.7, 0.8, and 0.9 kg/liter, respectively.
[c]Diluent contents typically range between 25-45%, by volume. Emissions may be linearly interpolated for any given type of cutback between these values.

Mitigation Techniques

No control devices are used to reduce evaporative emissions from cutback asphalts. Asphalt emulsions are typically used in place of cutback asphalts to eliminate VOC emissions.

References

1. R. Keller and R. Bohn. *Nonmethane Volatile Organic Emissions from Asphalt Cement and Liquified Asphalts*, EPA-450/3-78-124, U.S. Environmental Protection Agency, Research Triangle Park, NC, December 1978.

2. F. Kirwan and C. Maday. *Air Quality and Energy Conservation Benefits from Using Emulsions to Replace Asphalt Cutbacks in Certain Paving Operations*, EPA-450/2-78-004. U.S. Environmental Protection Agency, Research Triangle Park, NC, January 1978.

3. David W. Markwordt. *Control of Volatile Organic Compounds from Use of Cutback Asphalt*, EPA 450/2-77-037, U.S. Environmental Protection Agency, Research Triangle Park, NC, December 1977.

3.4.2 Asphaltic Concrete Plants

3.4.2 Asphaltic Concrete Plants

Source of Emissions Data

The following information was obtained from:

U.S. Environmental Protection Agency. 1995. *Compilation of Air Pollutant Emission Factors, Volume I: Stationary Point and Area Sources* (Fifth Edition--DRAFT). Section 11.1.

Estimating Emissions

General Description.[1-2,23,42-43] Hot mix asphalt (HMA) paving materials are a mixture of well-graded, high-quality aggregate (which can include reclaimed asphalt pavement [RAP]), and liquid asphalt cement, which is heated and mixed in measured quantities to produce HMA. Aggregate and RAP (if used) constitute over 92 percent by weight of the total mixture. Aside from the amount and grade of asphalt cement used, mix characteristics are determined by the relative amounts and types of aggregate and RAP used. A certain percentage of fine aggregate (less than 74 micrometers in physical diameter) is required for the production of good quality HMA.

Hot mix asphalt paving materials can be manufactured by batch mix plants, continuous mix (mix outside drum) plants, parallel flow drum mix plants, and counterflow drum mix plants. This order of listing generally reflects the chronological order of development and use within the HMA industry.

There are approximately 3,600 active asphalt plants in the United States. Of these, approximately 2,300 are batch plants, 1,000 are parallel flow drum mix plants, and 300 are counterflow drum mix plants. About 85 percent of plants being manufactured today are of the counterflow drum mix design, while batch plants and parallel flow drum mix plants account for 10 percent and 5 percent, respectively.

Continuous mix plants (type 2 above) represent a very small fraction of the plants in use (1/2 percent or less) and, therefore, are not discussed further nor are any data presented for this type of plant.

An HMA plant can be constructed as a permanent plant, a skid mounted (easily relocated) plant, or as a portable plant. All plants can have RAP processing capabilities. Virtually all of the plants manufactured today have RAP processing capability.

Batch Mix Plants. Figure 3.4.2-1 shows the batch mix HMA production process. Raw aggregate normally is stockpiled near the plant. The bulk aggregate moisture content typically stabilizes between 3 to 5 percent by weight.

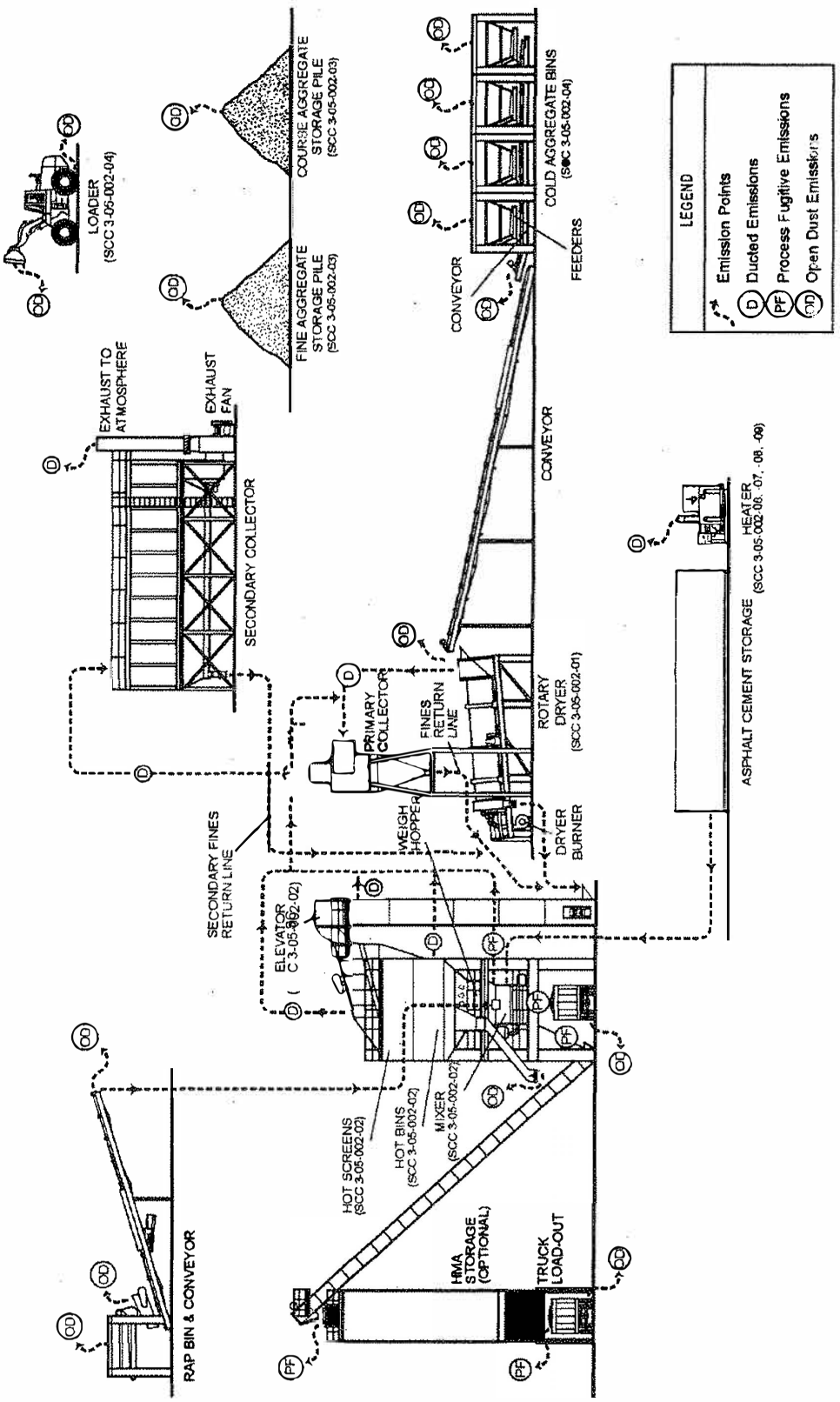

Figure 3.4.2-1. Batch Mix HMA Production Process

Processing begins as the aggregate is hauled from the storage piles and placed in the appropriate hoppers of the cold feed unit. The material is metered from the hoppers onto a conveyer belt and transported into a rotary dryer (typically gas- or oil-fired). Dryers are equipped with flights designed to shower the aggregate inside the drum to promote drying efficiency.

As the hot aggregate leaves the dryer, it drops into a bucket elevator and is transferred to a set of vibrating screens where it is classified into as many as four different grades (sizes) and dropped into individual "hot" bins according to size. To control aggregate size distribution in the final batch mix, the operator opens various hot bins over a weigh hopper until the desired mix and weight are obtained. Reclaimed asphalt pavement may be added at this point also. Concurrent with the aggregate being weighed, liquid asphalt cement is pumped from a heated storage tank to an asphalt bucket, where it is weighed to achieve the desired aggregate-to-asphalt cement ratio in the final mix.

The aggregate from the weigh hopper is dropped into the pugmill (mixer) and dry-mixed for 6 to 10 seconds. The liquid asphalt is then dropped into the pugmill where it is mixed for an additional period of time. Total mixing time is usually less than 60 seconds. Then the hot mix is conveyed to a hot storage silo or dropped directly into a truck and hauled to the job site.

Parallel Flow Drum Mix Plants. Figure 3.4.2-2 shows the parallel flow drum mix process. This process is a continuous mixing type process using proportioning cold feed controls for the process materials. The major difference between this process and the batch process is that the dryer is used not only to dry the material but also to mix the heated and dried aggregates with the liquid asphalt cement. Aggregate, which has been proportioned by gradations, is introduced to the drum at the burner end. As the drum rotates, the aggregates as well as the combustion products move toward the other end of the drum in *parallel.* Liquid asphalt cement flow is controlled by a variable flow pump that is electronically linked to the virgin aggregate and RAP weigh scales. The asphalt cement is introduced in the mixing zone midway down the drum in a lower temperature zone along with any RAP and PM from collectors.

The mixture is discharged at the end of the drum and conveyed to a surge bin or HMA storage silos. The exhaust gases also exit the end of the drum and pass on to the collection system.

Parallel flow drum mixers have an advantage in that mixing in the discharge end of the drum captures a substantial portion of the aggregate dust, therefore lowering the load on the downstream collection equipment. For this reason, most parallel flow drum mixers are followed only by primary collection equipment (usually a baghouse or venturi scrubber). However, because the mixing of aggregate and liquid asphalt cement occurs in the hot combustion product flow, organic emissions (gaseous and liquid aerosol) may be greater than in other processes.

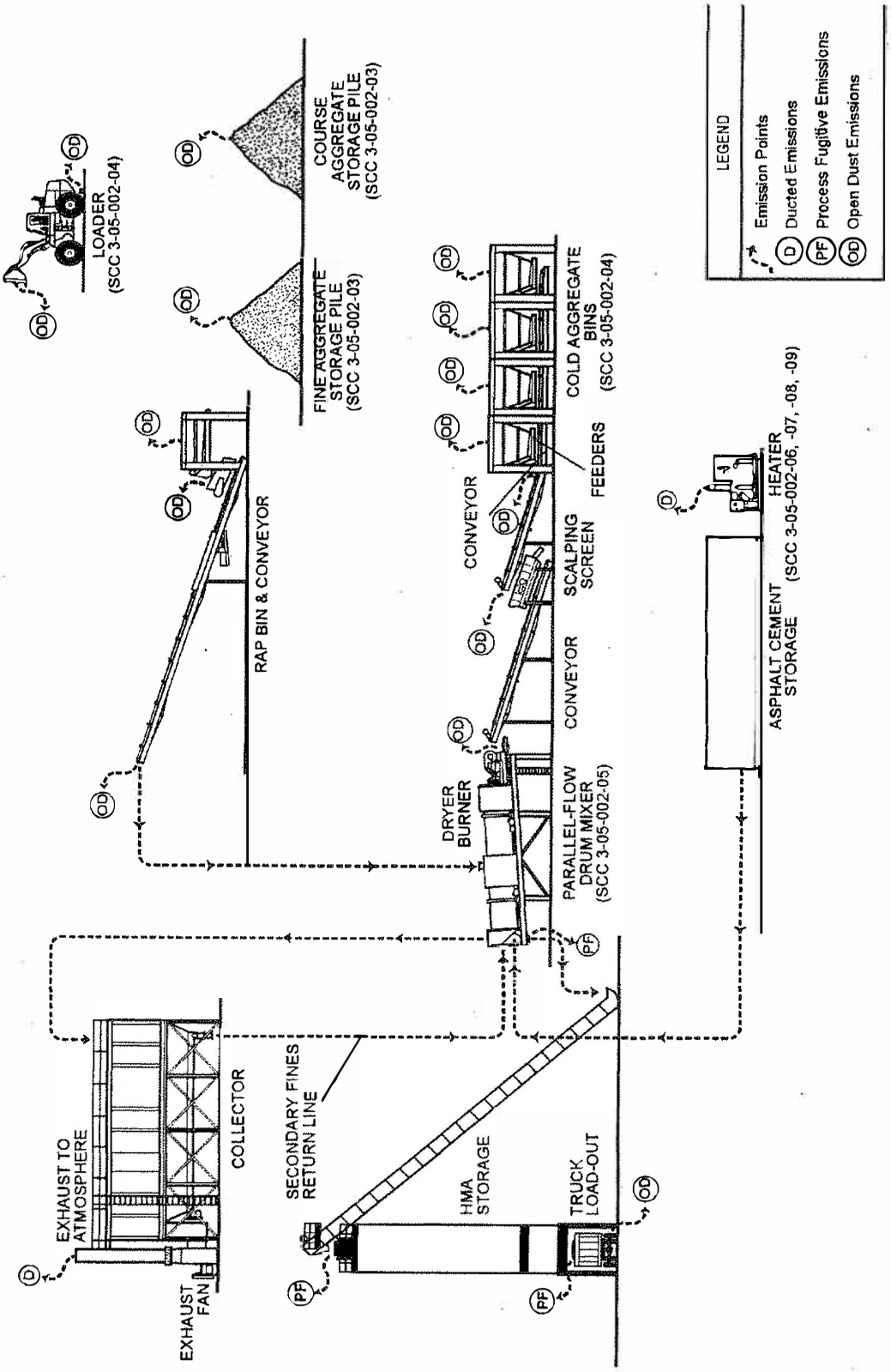

Figure 3.4.2-2 Parallel Flow Drum Mix Process

Counterflow Drum Mix Plants. Figure 3.4.2-3 shows a counterflow drum mix plant. In this type of plant, the material flow in the drum is opposite or *counterflow* to the direction of exhaust gases. In addition, the liquid asphalt cement mixing zone is located behind the burner flame zone so as to remove the materials from direct contact with hot exhaust gases.

Liquid asphalt cement flow is controlled by a variable flow pump that is electronically linked to the virgin aggregate and RAP weigh scales. It is injected into the mixing zone along with any RAP and particulate matter from primary and secondary collectors.

Because the liquid asphalt cement, virgin aggregate, and RAP are mixed in a zone removed from the exhaust gas stream, counterflow drum mix plants will likely have organic emissions (gaseous and liquid aerosol) that are lower than parallel flow drum mix plants. A counterflow drum mix plant can normally process RAP at ratios up to 50 percent with little or no observed effect upon emissions. Today's counterflow drum mix plants are designed for improved thermal efficiencies.

Recycle Processes. In recent years, the use of RAP has been initiated in the HMA industry. Reclaimed asphalt pavement significantly reduces the amount of new (virgin) rock and asphalt cement needed to produce HMA.

In the reclamation process, old asphalt pavement is removed from the road base. This material is then transported to the plant, and is crushed and screened to the appropriate size for further processing. The paving material is then heated and mixed with new aggregate (if applicable), and the proper amount of new asphalt cement is added to produce a high quality grade of HMA.

Emission Factor Data.[23,42-43] Emission points at batch and drum mix asphalt plants discussed below refer to Figures 3.4.2-1, -2, and -3 respectively.

Batch Mix Plants. As with most facilities in the mineral products industry, batch mix HMA plants have two major categories of emissions: those that are vented to the atmosphere through some type of stack, vent, or pipe (ducted sources), and those that are not confined to ducts and vents but are emitted directly from the source to the ambient air (fugitive sources). Ducted emissions are usually collected and transported by an industrial ventilation system with one or more fans or air movers, eventually to be emitted to the atmosphere through some type of stack. Fugitive emissions result from process and open sources and consist of a combination of gaseous pollutants and PM.

The most significant source of ducted emissions from batch mix HMA plants is the rotary drum dryer. Emissions from the dryer consist of water as steam evaporated from the aggregate, PM, and small amounts of VOCs of various species (including HAPs) derived from combustion exhaust gases.

Other potential process sources include the hot-side conveying, classifying, and mixing equipment, which are vented to either the primary dust collector along with the dryer gas or

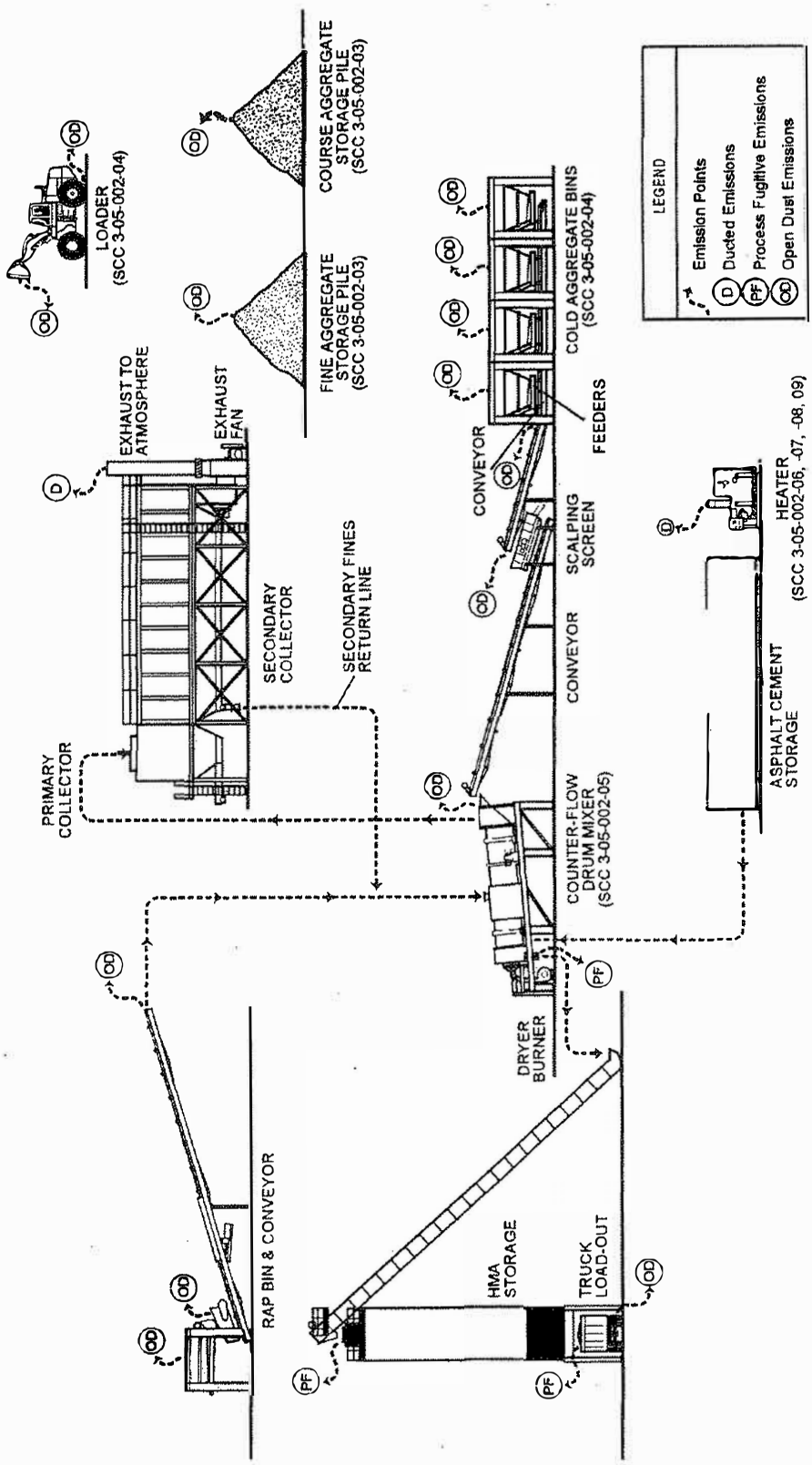

Figure 3.4.2-3 Counterflow Drum Mix Plant

to a separate dust collection system. The vents and enclosures that collect emissions from these sources are commonly called "fugitive air" or "scavenger" systems. The scavenger system may or may not have its own separate air mover device, depending on the particular facility. The emissions captured and transported by the scavenger system are mostly aggregate dust, but they may also contain gaseous VOCs and a fine aerosol of condensed liquid particles. This liquid aerosol is created by the condensation of gas into particles during cooling of organic vapors volatilized from the asphalt cement in the pugmill. The amount of liquid aerosol produced depends to a large extent on the temperature of the asphalt cement and aggregate entering the pugmill. Organic vapor and its associated aerosol are also emitted directly to the atmosphere as process fugitives during truck loadout, from the bed of the truck itself during transport to the job site, and from the asphalt storage tank. In addition to low molecular weight VOCs, these organic emission streams may contain small amounts of polycyclic compounds. Both the low molecular weight VOCs and the polycyclic organic compounds can include HAPs. The ducted emissions from the heated asphalt storage tanks may include VOCs and combustion products from the tank heater.

There are also a number of fugitive dust sources associated with batch mix HMA plants, including vehicular traffic generating fugitive dust on paved and unpaved roads, aggregate material handling, and other aggregate processing operations. Fugitive dust may range from 0.1 μm to more than 300 μm in aerodynamic diameter. On average, 5 percent of cold aggregate feed is less than 74 μm (minus 200 mesh). Fugitive dust that may escape collection before primary control generally consists of PM with 50 to 70 percent of the total mass less than 74 μm. Uncontrolled PM emission factors for various types of fugitive sources in HMA plants are addressed in Section 3.2.3 of this document, "Heavy Construction Operations."

Parallel Flow Drum Mix Plants. The most significant ducted source of emissions is the rotary drum dryer. Emissions from the drum consist of water as steam evaporated from the aggregate, PM, and small amounts of VOCs of various species (including HAPs) derived from combustion exhaust gases, liquid asphalt cement, and RAP, if used. The VOCs result from incomplete combustion and from the heating and mixing of liquid asphalt cement inside the drum. The processing of RAP materials may increase VOC emissions because of an increase in mixing zone temperature during processing.

Counterflow Drum Mix Plants. The most significant ducted source of emissions is the rotary drum dryer in a counterflow drum mix plant. Emissions from the drum consist of water as steam evaporated from the aggregate, PM, and small amounts of VOCs of various species (including HAPs) derived from combustion exhaust gases, liquid asphalt cement, and RAP, if used.

Because liquid asphalt cement, aggregate, and sometimes RAP are mixed in a zone not in contact with the hot exhaust gas stream, counterflow drum mix plants will likely have lower VOC emissions than parallel flow drum mix plants. The organic compounds that are emitted from counterflow drum mix plants are likely products of a slight inefficient combustion, and can include HAPs.

Parallel and Counterflow Drum Mix Plants. Process fugitive emissions associated with batch plant hot screens, elevators and the pugmill are not present in the drum mix processes. However, there may be minimal fugitive VOC emissions from the transport and handling of the hot mix from the drum mixer to the storage silo and also from the load out operations to the delivery trucks. Since the drum process is continuous, these plants must have surge bins or storage silos. The fugitive dust sources associated with drum mix plants are similar to those of batch mix plants with regard to truck traffic and aggregate material feed and handling operations.

Tables 3.4.2-1 and -2 present emission factors for filterable PM and PM_{10}, condensible PM, and total PM for batch mix HMA plants. The emission factors are based on the type of control technology employed, as well as the type of fuel used to fire the dryer. Particle size data for batch mix HMA plants, also based on the control technology used, are shown in Table 3.4.2-3. Tables 3.4.2-4 and -5 present filterable PM and PM_{10}, condensible PM, and total PM emission factors for drum mix HMA plants. The emission factors are based on the type of control technology employed, as well as the type of fuel used to fire the dryer. Particle size data for drum mix HMA plants, also based on the control technology used, are shown in Table 3.4.2-6. Tables 3.4.2-7, -8, -9, and -10 present emission factors for CO, CO_2, NO_x, SO_2, and total organic compounds from batch and drum mix plants.

Emission Calculations. The pollutant emissions from asphaltic concrete paving plants are estimated by summing the emissions, by pollutant, from all the individual processing operations. The total emissions can be estimated with the following equation:

$$E = \sum (EF \cdot T)_{each\ process}$$

where E = Particulate daily emissions, kg/day (lb/day)
EF = Emission factor, kg/Mg (lb/ton)
T = Amount of material throughput (for each operation) processed each day, Mg/day (tons/day)

An example calculation for determining NO_x emissions from a batch mix HMA plant is given below.

Example

A batch mix HMA facility will be temporarily located near the proposed construction site of a highway. Estimate the NO_x emissions from a gas-fired rotary dryer assuming 80 tons of asphalt will be processed at this facility.

$$E = 0.025 \frac{lb}{ton} \cdot 80 \frac{tons}{day}$$

$$= 2.0 \frac{lb}{day} \text{ of } NO_x$$

Please note: The example above quantifies emissions from only one process of the batch mix HMA facility. Section 3.5.1 of this document, "Crushed Stone Processing," details how emissions from a facility with multiple emission sources can be totaled.

Hazardous Air Pollutants and Trace Elements. Table 3.4.2-11 presents organic pollutant emission factors for batch plants. Tables 3.4.2-12 and -13 present organic pollutant emission factors for drum mix plants. Metals emissions factors are summarized in Tables 3.4.2-14 and -15 for batch and drum mix plants, respectively.

Mitigation Techniques[23,42-43]

Batch Mix Plants. The choice of applicable control equipment for the dryer exhaust and vent line ranges from dry mechanical collectors to scrubbers and fabric collectors. Attempts to apply electrostatic precipitators have met with little success. Practically all plants use primary dust collection equipment with large diameter cyclones, skimmers, or settling chambers. These chambers are often used as classifiers to return collected material to the hot elevator and to combine it with the drier aggregate. To capture remaining PM, the primary collector effluent is ducted to a secondary collection device. Most plants use either a baghouse or a venturi scrubber for secondary emissions control.

Mitigation techniques of fugitive dust sources (that is, truck traffic on paved and unpaved roads, aggregate material feed and handling) are summarized in Sections 3.2.1, 3.2.2, and 3.2.4 of this report and Section 13.2.4 of *AP-42*, Fifth Edition.

Parallel Flow Drum Mix Plants. As the exhaust stream from the rotary drum dryer discharges from the process stack, the some of the VOC emissions cool and condense to form a fine liquid aerosol or "blue smoke" plume. A number of process modifications or restrictions have been introduced to reduce blue smoke including installation of flame shields, rearrangement of flights inside the drum, adjustments of the asphalt injection point, and other design changes.

Parallel and Counterflow Drum Mix Plants. Mitigation techniques of fugitive dust sources (that is, truck traffic, aggregate material feed and handling) are similar to those of batch mix plants, summarized above.

Table 3.4.2-1
Emission Factors for Batch Mix Hot Mix Asphalt Plants[a]
(Metric Units)

Process	Filterable PM				Condensible PM						Total PM			
	PM	Emission Factor Rating	PM_{10}[b]	Emission Factor Rating	Inorganic	Emission Factor Rating	Organic	Emission Factor Rating	Total	Emission Factor Rating	PM	Emission Factor Rating	PM_{10}	Emission Factor Rating
Dryer (gas-fired) (SCC 3-05-002-01)														
Uncontrolled	16[c]	E	2.2	E	0.0017[d]	D	0.00039[d]	D	0.0021	D	16	E	2.2	E
Low-energy scrubber[e]	0.039	D	ND		0.0017	D	ND		ND		ND		ND	
Venturi scrubber[e]	0.026	E	ND		ND		ND		ND		ND		ND	
Fabric filter	0.020[f]	D	0.0080	D	0.0014[g]	D	0.00039[h]	D	0.0018[h]	D	0.022[j]	D	0.0098	D
Dryer (oil-fired) (SCC 3-05-002-01)														
Uncontrolled	16[c]	E	2.2	E	0.0083[d]	D	ND		0.022[d]	D	16	E	2.2	E
Venturi scrubber[e]	0.026	E	ND		0.0083	E	ND		ND		ND		ND	
Fabric filter	0.020[e]	D	0.0080	D	ND		ND		0.022[k]	D	0.042[m]	D	0.030	D

[a]Filterable PM emission factors were developed from tests on dryers fired with several different fuels. ND = no data available. All emission factors in kg/Mg of product. SCC = Source Classification Code.
[b]Particle size data from Reference 23 were used in conjunction with the filterable PM emission factors shown.
[c]Reference 5.
[d]Although no emission test data are available for uncontrolled condensible PM, values are assumed to be equal to the maximum controlled value measured.
[e]Reference 15.
[f]References 15, 24, 40-41.
[g]Reference 24.
[h]References 24, 39.
[j]References 15, 24, 39, 40-41.
[k]Reference 39.
[m]Reference 40.

Table 3.4.2-2
Emission Factors For Batch Mix Hot Mix Asphalt Plants[a]
(English Units)

Process	Filterable PM				Condensible PM						Total PM			
	PM	Emission Factor Rating	PM_{10}[b]	Emission Factor Rating	Inorganic	Emission Factor Rating	Organic	Emission Factor Rating	Total	Emission Factor Rating	PM	Emission Factor Rating	PM_{10}	Emission Factor Rating
Dryer (gas-fired) (SCC 3-05-002-01)														
Uncontrolled	32[c]	E	4.5	E	0.0033[d]	D	0.00078[d]	D	0.0041	D	32	E	4.5	E
Low-energy scrubber[e]	0.077	D	ND		0.0033	D	ND		ND		ND		ND	
Venturi scrubber[e]	0.052	E	ND		ND		ND		ND		ND		ND	
Fabric filter	0.040[f]	D	0.016	D	0.0027[g]	D	0.00078[g]	D	0.0035[h]	D	0.044[j]	D	0.020	D
Dryer (oil-fired) (SCC 3-05-002-01)														
Uncontrolled	32[c]	E	4.5	E	0.017[d]	E	ND		0.045[d]	D	32	E	4.5	E
Venturi scrubber[e]	0.052	E	ND		0.017	E	ND		ND		ND		ND	
Fabric filter	0.040[e]	D	0.016	D	ND		ND		0.045[k]	D	0.08[m]	D	0.061	D

[a]Filterable PM emission factors were developed from tests on dryers fired with several different fuels. ND = no data available. All emission factors in lb/ton of product. SCC = Source Classification Code.
[b]Particle size data from Reference 23 were used in conjunction with the filterable PM emission factors shown.
[c]Reference 5.
[d]Although no emission test data are available for uncontrolled condensible PM, values are assumed to be equal to the maximum controlled value measured.
[e]Reference 15.
[f]References 15, 24, 40-41.
[g]Reference 24.
[h]References 24, 39.
[j]References 15, 24, 39, 40-41.
[k]Reference 39.
[m]Reference 40.

Table 3.4.2-3
Summary of Particle Size Distribution For Batch Mix Hot Mix Asphalt Plants[a]

Particle size, μm[b]	Cumulative mass less than or equal to stated size (%)[c]				
	Uncontrolled	Cyclone collectors	Multiple centrifugal scrubbers	Gravity spray towers	Fabric filters
2.5	0.83	5.0	67	21	33
5.0	3.5	11	74	27	36
10.0	14	21	80	37	40
15.0	23	29	83	39	47
20.0	30	36	84	41	54

[a]Reference 23, Table 3-36. Rounded to two significant figures.
[b]Aerodynamic diameter.
[c]Applies only to the mass of filterable PM.

Table 3.4.2-4
Emission Factors For Drum Mix Hot Mix Asphalt Plants[a]
(Metric Units)

Emission Factor Rating: D

Process	Filterable PM		Condensible PM			Total PM[b]	
	PM	PM_{10}[c]	Inorganic	Organic	Total	PM	PM_{10}
Dryer (gas-fired) (SCC 3-05-002-05)							
Uncontrolled	9.4[d]	2.2	0.014[e]	0.027[f]	0.041	9.4	2.2
Venturi scrubber	0.017[g]	ND	ND	0.010[f]	ND	ND	ND
Fabric filter	0.0070[h]	0.0022	ND	ND	0.0019[j]	0.0089	0.0041
Dryer (oil-fired) (SCC 3-05-002-05)							
Uncontrolled	9.4[d]	2.2	0.012[e]	0.0013[e]	0.013[e]	9.4	2.2
Venturi scrubber	0.017[g]	ND	ND	ND	ND	ND	ND
Fabric filter	0.0070[h]	0.0022	0.012[k]	0.0013[k]	0.013[k]	0.020	0.015

[a]Tests included dryers that were processing reclaimed asphalt pavement (RAP). Because of the limited data available, the effect of RAP processing on emissions could not be determined. Filterable PM emission factors were developed from tests on dryers firing several different fuels. ND = no data available. All emission factors in kg/Mg of product. SCC = Source Classification Code.
[b]Total PM emission factors are the sum of the filterable PM and total condensible PM emission factors. Total PM_{10} emission factors are the sum of the filterable PM_{10} and total condensible PM emission factors.
[c]Particle size data from Reference 23 were used in conjunction with the filterable PM emission factors shown.
[d]References 31, 36-38.
[e]Although no emission test data are available for uncontrolled condensible PM, values are assumed to be equal to the maximum controlled value measured.
[f]References 36-37.
[g]References 29, 32, 36, 37, 40.
[h]References 25-28, 31, 33, 40. EMISSION FACTOR RATING: C.
[j]Reference 39.
[k]Reference 25, 39.

Table 3.4.2-5
Emission Factors For Drum Mix Hot Mix Asphalt Plants[a]
(English Units)

Emission Factor Rating: D

Process	Filterable PM		Condensible PM			Total PM[b]	
	PM	PM_{10}[c]	Inorganic	Organic	Total	PM	PM_{10}
Dryer (gas-fired) (SCC 3-05-002-05)							
Uncontrolled	19[d]	4.3	0.027[e]	0.054[f]	0.081	19	4.4
Venturi scrubber	0.033[g]	ND	ND	0.020[f]	ND	ND	ND
Fabric filter	0.014[h]	0.0045	ND	ND	0.0037[j]	0.018	0.0082
Dryer (oil-fired) (SCC 3-05-002-05)							
Uncontrolled	19[d]	4.3	0.023[e]	0.0026[e]	0.026[e]	19	4.3
Venturi scrubber	0.033[g]	ND	ND	ND	ND	ND	ND
Fabric filter	0.014[h]	0.0045	0.023[k]	0.0026[k]	0.026[k]	0.040	0.031

[a]Tests included dryers that were processing reclaimed asphalt pavement (RAP). Because of the limited data available, the effect of RAP processing on emissions could not be determined. Filterable PM emission factors were developed from tests on dryers firing several different fuels. ND = no data available. All emission factors in lb/ton of product. SCC = Source Classification Code.

[b]Total PM emission factors are the sum of the filterable PM and total condensible PM emission factors. Total PM_{10} emission factors are the sum of the filterable PM_{10} and total condensible PM emission factors.

[c]Particle size data from Reference 23 were used in conjunction with the filterable PM emission factors shown.

[d]References 31, 36-38.

[e]Although no emission test data are available for uncontrolled condensible PM, values are assumed to be equal to the maximum controlled value measured.

[f]References 36-37.

[g]References 29, 32, 36, 37, 40.

[h]References 25-28, 31, 33, 40. EMISSION FACTOR RATING: C.

[j]Reference 39.

[k]Reference 25, 39.

Table 3.4.2-6
Summary of Particle Size Distribution For Drum Mix Hot Mix Asphalt Plants[a]

Particle size, μm[b]	Cumulative mass less than or equal to stated size (%)[c]	
	Uncontrolled	Fabric filters[d]
2.5	5.5	11
10.0	23	32
15.0	27	35

[a]Reference 23, Table 3-35. Rounded to two significant figures.
[b]Aerodynamic diameter.
[c]Applies only to the mass of filterable PM.
[d]Includes data from two out of eight tests where about 30 percent reclaimed asphalt pavement was processed using a split feed process.

Table 3.4.2-7
Emission Factors For Batch Mix Hot Mix Asphalt Plants[a]
(Metric Units)

Emission Factor Rating: D

Process	CO	CO_2	NO_x	SO_2	TOC[b]
Dryer (gas-fired) (SCC 3-05-002-01)	0.17[c]	17[d]	0.013[c]	0.0025[e]	0.0084[f]
Dryer (oil-fired) (SCC 3-05-002-01)	0.035[e]	19[g]	0.084[e]	0.12[e]	0.023[f]

[a]Emission factors represent uncontrolled emissions unless otherwise noted. SCC = Source Classification Code. All emission factors in kg/Mg of product.
[b]Emission factor represents TOC as methane, and is based on EPA Method 25A test data.
[c]References 24, 34, 39.
[d]References 15, 24, 39.
[e]Reference 39.
[f]References 24, 39.
[g]References 15, 39.

Table 3.4.2-8
Emission Factors For Batch Mix Hot Mix Asphalt Plants[a]
(English Units)

Emission Factor Rating: D

Process	CO	CO_2	NO_x	SO_2	TOC[b]
Dryer (gas-fired) (SCC 3-05-002-01)	0.34[c]	35[d]	0.025[c]	0.0050[e]	0.017[f]
Dryer (oil-fired) (SCC 3-05-002-01)	0.069[e]	39[g]	0.17[e]	0.24[e]	0.046[f]

[a]Emission factors represent uncontrolled emissions unless otherwise noted. SCC = Source Classification Code. All emission factors in lb/ton of product.
[b]Emission factor represents TOC as methane, and is based on EPA Method 25A test data.
[c]References 24, 34, 39.
[d]References 15, 24, 39.
[e]Reference 39.
[f]References 24, 39.
[g]References 15, 39.

Table 3.4.2-9
Emission Factors For Drum Mix Hot Mix Asphalt Plants[a]
(Metric Units)

Emission Factor Rating: D

Process	CO	CO_2	NO_x	SO_2	TOC[b]
Dryer (gas-fired) (SCC 3-05-002-05)	0.028[c]	14[d]	0.015[c]	0.0017[c]	0.025[c]
Dryer (oil-fired) (SCC 3-05-002-05)	0.018[e]	19[f]	0.038[g]	0.028[g]	0.035[g]

[a]Emission factors represent uncontrolled emissions unless otherwise noted. Tests included dryers that were processing reclaimed asphalt pavement (RAP). Because of limited data, the effect of RAP processing on emissions could not be determined. SCC = Source Classification Code. All emission factors in kg/Mg of product.
[b]Emission factor represents TOC as methane, and is based on EPA Method 25A test data.
[c]Reference 39. Includes data from both parallel flow and counterflow drum mix dryers. Organic compound emissions from counterflow systems are expected to be smaller than from parallel flow systems. However, the available data are insufficient to accurately quantify the difference in these emissions.
[d]References 30, 39.
[e]Reference 25.
[f]References 25-27, 29, 32-33, 39.
[g]References 25, 39. Includes data from both parallel flow and counterflow drum mix dryers. Organic compound emissions from counterflow systems are expected to be smaller than from parallel flow systems. However, the available data are insufficient to accurately quantify the difference in these emissions.

Table 3.4.2-10
Emission Factors For Drum Mix Hot Mix Asphalt Plants[a]
(English Units)

Emission Factor Rating: D

Process	CO	CO_2	NO_x	SO_2	TOC[b]
Dryer (gas-fired) (SCC 3-05-002-05)	0.056[c]	27[d]	0.030[c]	0.0033[c]	0.051[c]
Dryer (oil-fired) (SCC 3-05-002-05)	0.036[e]	37[f]	0.075[g]	0.056[g]	0.069[g]

[a]Emission factors represent uncontrolled emissions unless otherwise noted. Tests included dryers that were processing reclaimed asphalt pavement (RAP). Because of limited data, the effect of RAP processing on emissions could not be determined. SCC = Source Classification Code. All emission factors in lb/ton of product.

[b]Emission factor represents TOC as methane, and is based on EPA Method 25A test data.

[c]Reference 39. Includes data from both parallel flow and counterflow drum mix dryers. Organic compound emissions from counterflow systems are expected to be smaller than from parallel flow systems. However, the available data are insufficient to accurately quantify the difference in these emissions.

[d]References 30, 39.

[e]Reference 25.

[f] References 25-27, 29, 32-33, 39.

[g]References 25 and 39. Includes data from both parallel flow and counterflow drum mix dryers. Organic compound emissions from counterflow systems are expected to be smaller than from parallel flow systems. However, the available data are insufficient to accurately quantify the difference in these emissions.

Table 3.4.2-11
Emission Factors For Organic Pollutant Emissions From Batch Mix Hot Mix Asphalt Plants[a]

Process	Pollutant		Emission factor		Emission Factor Rating	Ref. Nos.
	CASRN	Name	kg/Mg	lb/ton		
Natural gas-fired dryer (SCC 3-05-002-01)	91-57-6	2-Methylnaphthalene[b]	3.8×10^{-5}	7.7×10^{-5}	D	24,39
	83-32-9	Acenaphthene[b]	6.2×10^{-7}	1.2×10^{-6}	D	34,39
	208-96-8	Acenaphthylene[b]	4.3×10^{-7}	8.6×10^{-7}	D	34,39
	75-07-0	Acetaldehyde	0.00032	0.00064	D	24
	67-64-1	Acetone	0.0032	0.0064	D	24
	120-12-7	Anthracene[b]	1.5×10^{-7}	3.1×10^{-7}	D	34,39
	100-52-7	Benzaldehyde	6.4×10^{-5}	0.00013	D	24
	71-43-2	Benzene	0.00017	0.00035	D	24,39
	56-55-3	Benzo(a)anthracene[b]	2.3×10^{-9}	4.5×10^{-9}	D	39
	205-99-2	Benzo(b)fluoranthene[b]	2.3×10^{-9}	4.5×10^{-9}	D	39
	207-08-9	Benzo(k)fluoranthene[b]	1.2×10^{-8}	2.4×10^{-8}	E	34
	78-84-2	Butyraldehyde/ Isobutyraldehyde	1.5×10^{-5}	3.0×10^{-5}	D	24
	218-01-9	Chrysene[b]	3.1×10^{-9}	6.1×10^{-9}	D	39
	4170-30-3	Crotonaldehyde	1.5×10^{-5}	2.9×10^{-5}	D	24
	100-41-4	Ethyl benzene	0.0016	0.0033	D	24,39
	206-44-0	Fluoranthene[b]	1.6×10^{-7}	3.1×10^{-7}	D	34,39
	86-73-7	Fluorene[b]	9.8×10^{-7}	2.0×10^{-6}	D	34,39
	50-00-0	Formaldehyde	0.00043	0.00086	D	24,39
	66-25-1	Hexanal	1.2×10^{-5}	2.4×10^{-5}	D	24
	74-82-8	Methane	0.0060	0.012	D	39
	91-20-3	Naphthalene[b]	2.1×10^{-5}	4.2×10^{-5}	D	34,39
	85-01-8	Phenanthrene[b]	1.6×10^{-6}	3.3×10^{-6}	D	34,39
	129-00-0	Pyrene[b]	3.1×10^{-8}	6.2×10^{-8}	D	34,39
	106-51-4	Quinone	0.00014	0.00027	D	24
	108-88-3	Toluene	0.00088	0.0018	D	24,39
	1330-20-7	Xylene	0.0021	0.0043	D	24,39
Oil-fired dryer (SCC 3-05-002-01)	91-57-6	2-Methylnaphthalene[b]	3.0×10^{-5}	6.0×10^{-5}	D	39
	206-44-0	Fluoranthene[b]	1.2×10^{-5}	2.4×10^{-5}	D	39
	50-00-0	Formaldehyde	0.0016	0.0032	E	39,40
		Methane	0.0022	0.0043	D	39
	91-20-3	Naphthalene[b]	2.2×10^{-5}	4.5×10^{-5}	D	39
	85-01-8	Phenanthrene[b]	1.8×10^{-5}	3.7×10^{-5}	E	39
	129-00-0	Pyrene[b]	2.7×10^{-5}	5.5×10^{-5}	D	39

[a]Emission factors in kg/Mg (lb/ton) of hot mix asphalt produced. CASRN = Chemical Abstracts Service Registry Number. Factors represent uncontrolled emissions unless otherwise noted. SCC = Source Classification Code.

[b]Emissions controlled by a fabric filter. Compound is classified as polycyclic organic matter (POM) as defined in the 1990 Clean Air Act Amendments (CAAA).

Table 3.4.2-12
Emission Factors For Organic Pollutant Emissions From Drum Mix Hot Mix Asphalt Plants[a]

(page 1 of 2)

Process	Pollutant		Emission factor		Emission Factor Rating	Ref.
	CASRN	Name	kg/Mg	lb/ton		
Natural gas- or propane-fired dryer[b] (SCC 3-05-002-05)	91-58-7	2-Chloronaphthalene[c]	8.9×10^{-7}	1.8×10^{-6}	D	39
	91-57-6	2-Methylnaphthalene[c]	3.7×10^{-5}	7.4×10^{-5}	D	39
	83-32-9	Acenaphthene[c]	6.4×10^{-7}	1.3×10^{-6}	D	35,39
	208-96-8	Acenaphthylene[c]	4.2×10^{-6}	8.4×10^{-6}	D	35,39
	120-12-7	Anthracene[c]	1.0×10^{-7}	2.1×10^{-7}	D	35,39
	71-43-2	Benzene	0.00060	0.0012	D	39
	56-55-3	Benzo(a)anthracene[c]	1.0×10^{-7}	2.0×10^{-7}	D	39
	50-32-8	Benzo(a)pyrene[c]	4.6×10^{-9}	9.2×10^{-9}	D	39
	205-99-2	Benzo(b)fluoranthene[c]	5.1×10^{-8}	1.0×10^{-7}	D	35,39
	192-97-2	Benzo(e)pyrene[c]	5.2×10^{-8}	1.0×10^{-7}	D	39
	191-24-2	Benzo(g,h,i)perylene[c]	1.9×10^{-8}	3.9×10^{-8}	D	39
	207-08-9	Benzo(k)fluoranthene[c]	2.6×10^{-8}	5.3×10^{-8}	D	39
	218-01-9	Chrysene[c]	1.8×10^{-7}	3.5×10^{-7}	D	39
	53-70-3	Dibenz(a,h)anthracene[c]	1.3×10^{-9}	2.7×10^{-9}	E	39
	100-41-4	Ethylbenzene	0.00015	0.00029	E	39
	206-44-0	Fluoranthene[c]	3.0×10^{-7}	5.9×10^{-7}	D	35,39
	86-73-7	Fluorene[c]	2.7×10^{-6}	5.3×10^{-6}	D	35,39
	50-00-0	Formaldehyde	0.0018	0.0036	D	35,39
	50-00-0	Formaldehyde[d]	0.00079	0.0016	E	40
	193-39-5	Indeno(1,2,3-cd)pyrene[c]	3.6×10^{-9}	7.3×10^{-9}	D	39
	74-82-8	Methane	0.010	0.021	D	39
	71-55-6	Methyl chloroform	2.4×10^{-5}	4.8×10^{-5}	E	35
	91-20-3	Naphthalene[c]	2.4×10^{-5}	4.8×10^{-5}	D	35,39
	198-55-0	Perylene[c]	6.2×10^{-9}	1.2×10^{-8}	E	39
	85-01-8	Phenanthrene[c]	4.2×10^{-6}	8.4×10^{-6}	D	35,39
	129-00-0	Pyrene[c]	2.3×10^{-7}	4.6×10^{-7}	D	35,39
	108-88-3	Toluene	0.00010	0.00020	D	35,39
	1330-20-7	Xylene	0.00020	0.00040	D	39

Table 3.4.2-12
Emission Factors For Organic Pollutant Emissions From Drum Mix Hot Mix Asphalt Plants[a]

Process	Pollutant		Emission factor		Emission Factor Rating	Ref.
	CASRN	Name	kg/Mg	lb/ton		
Oil-fired dryer[c] (SCC 3-05-002-05)	91-57-6	2-Methylnaphthalene[c]	8.5×10^{-5}	0.00017	D	39
	208-96-8	Acenaphthylene[c]	1.1×10^{-5}	2.2×10^{-5}	D	39
	75-07-0	Acetaldehyde	0.00065	0.0013	D	25
	67-64-1	Acetone	0.00042	0.00083	D	25
	107-02-8	Acrolein	1.3×10^{-5}	2.6×10^{-5}	D	25
	120-12-7	Anthracene[c]	1.8×10^{-6}	3.6×10^{-6}	D	39
	100-52-7	Benzaldehyde	5.5×10^{-5}	0.00011	D	25
	71-43-2	Benzene	0.00020	0.00041	D	25
	78-84-2	Butyraldehyde/ Isobutyraldehyde	8.0×10^{-5}	0.00016	D	25
	4170-30-3	Crotonaldehyde	4.3×10^{-5}	8.6×10^{-5}	D	25
	100-41-4	Ethylbenzene	0.00019	0.00038	D	25
	86-73-7	Fluorene[c]	8.5×10^{-6}	1.7×10^{-5}	D	39
	50-00-0	Formaldehyde	0.0012	0.0024	D	25,39
	50-00-0	Formaldehyde[f]	0.00026	0.00052	E	40
	66-25-1	Hexanal	5.5×10^{-5}	0.00011	D	25
	590-86-3	Isovaleraldehyde	1.6×10^{-5}	3.2×10^{-5}	D	25
	74-82-8	Methane	0.0096	0.020	D	25,39
	78-93-3	Methyl Ethyl Ketone	1.0×10^{-5}	2.0×10^{-5}	D	25
	91-20-3	Naphthalene[c]	0.00016	0.00031	D	25,39
	85-01-8	Phenanthrene[c]	2.8×10^{-5}	5.5×10^{-5}	D	39
	123-38-6	Propionaldehyde	6.5×10^{-5}	0.00013	D	25
	129-00-0	Pyrene[c]	1.5×10^{-6}	3.0×10^{-6}	E	39
	106-51-4	Quinone	8.0×10^{-5}	0.00016	D	25
	108-88-3	Toluene	0.00037	0.00075	D	25
	110-62-3	Valeraldehyde	3.4×10^{-5}	6.7×10^{-5}	D	25
	1330-20-7	Xylene	8.2×10^{-5}	0.00016	D	25

[a]Emission factors in kg/Mg and lb/ton of hot mix asphalt produced. Includes data from both parallel flow and counterflow drum mix dryers. Organic compound emissions from counterflow systems are expected to be smaller than from parallel flow systems. However, the available data are insufficient to accurately quantify the difference in these emissions. CASRN = Chemical Abstracts Service Registry Number. SCC = Source Classification Code.

[b]Tests included dryers that were processing reclaimed asphalt pavement (RAP). Because of limited data, the effect of RAP processing on emissions could not be determined.

[c]Emissions controlled by a fabric filter. Compound is classified as polycyclic organic matter (POM) as defined in the 1990 CAA.

[d]Emissions controlled by a wet scrubber.

Table 3.4.2-13
Emission Factors For Organic Pollutant Emissions From Hot Mix Asphalt Hot Oil Heaters[a]

Process	Pollutant		Emission factor		Emission Factor Rating	Ref.
	CASRN	Name	kg/l	lb/gal		
Hot oil heater fired with No. 2 fuel oil (SCC 3-05-002-08)	83-32-9	Acenaphthene[b]	6.4×10^{-8}	5.3×10^{-7}	E	34
	208-96-8	Acenaphthylene[b]	2.4×10^{-8}	2.0×10^{-7}	E	34
	120-12-7	Anthracene[b]	2.2×10^{-8}	1.8×10^{-7}	E	34
	205-99-2	Benzo(b)fluoranthene[b]	1.2×10^{-8}	1.0×10^{-7}	E	34
	206-44-0		5.3×10^{-9}	4.4×10^{-8}	E	34
	86-73-7	Fluoranthene[b]	3.8×10^{-9}	3.2×10^{-8}	E	34
	50-00-0	Fluorene[b]	0.0032	0.027	E	34
	91-20-3	Formaldehyde	2.0×10^{-6}	1.7×10^{-5}	E	34
	85-01-8	Naphthalene[b]	5.9×10^{-7}	4.9×10^{-6}	E	34
	129-00-0	Phenanthrene[b]	3.8×10^{-9}	3.2×10^{-8}	E	34
	19408-74-3	Pyrene[b]	9.1×10^{-14}	7.6×10^{-13}	E	34
	39227-28-6	1,2,3,7,8,9-HxCDD	8.3×10^{-14}	6.9×10^{-13}	E	34
		1,2,3,4,7,8-HxCDD	7.4×10^{-13}	6.2×10^{-12}	E	34
	35822-46-9	HxCDD's	1.8×10^{-12}	1.5×10^{-11}	E	34
		1,2,3,4,6,7,8-HpCDD	2.4×10^{-12}	2.0×10^{-11}	E	34
	3268-87-9	HpCDD's	1.9×10^{-11}	1.6×10^{-10}	E	34
		OCDD's	4.0×10^{-13}	3.3×10^{-12}	E	34
		TCDF's[b]	5.8×10^{-14}	4.8×10^{-13}	E	34
		PeCDF's[b]	2.4×10^{-13}	2.0×10^{-12}	E	34
		HxCDF's[b]	1.2×10^{-12}	9.7×10^{-12}	E	34
	67562-39-4	HpCDF's[b]	4.2×10^{-13}	3.5×10^{-12}	E	34
	39001-02-0	1,2,3,4,6,7,8-HpCDF	1.4×10^{-12}	1.2×10^{-11}	E	34
		OCDF's				

[a]Emission factors in kg/l and lb/gal of fuel consumed. Includes data from both parallel flow and counterflow drum mix dryers. Organic compound emissions from counterflow systems are expected to be smaller than from parallel flow systems. However, the available data are insufficient to accurately quantify the difference in these emissions. CASRN = Chemical Abstracts Service Registry Number. SCC = Source Classification Code.
[b]Compound is classified as polycyclic organic matter (POM) as defined in the 1990 CAA.

Table 3.4.2-14
Emission Factors For Metal Emissions From Batch Mix Hot Mix Asphalt Plants[a]

Process	Pollutant	Emission factor		Emission Factor Rating	Ref. No.
		kg/Mg	lb/ton		
Dryer (SCC 3-05-002-01)	Arsenic	3.3×10^{-7}	6.6×10^{-7}	E	34,40
	Barium	7.3×10^{-7}	1.5×10^{-6}	D	24
	Beryllium	1.1×10^{-7}	2.2×10^{-7}	E	34
	Cadmium	4.2×10^{-7}	8.4×10^{-7}	D	24,34
	Chromium	4.5×10^{-7}	8.9×10^{-7}	D	24
	Copper	1.8×10^{-6}	3.7×10^{-6}	D	24,34
	Hexavalent chromium	4.9×10^{-9}	9.7×10^{-9}	E	34
	Lead	3.7×10^{-7}	7.4×10^{-7}	D	24,34
	Manganese	5.0×10^{-6}	9.9×10^{-6}	D	24,34
	Mercury	2.3×10^{-7}	4.5×10^{-7}	D	34
	Nickel	2.1×10^{-6}	4.2×10^{-6}	D	24,34
	Selenium	4.6×10^{-8}	9.2×10^{-8}	E	34
	Zinc	3.4×10^{-6}	6.8×10^{-6}	D	24,34

[a]Emission factors in kg/Mg and lb/ton of hot mix asphalt produced. Emissions controlled by a fabric filter. SCC = Source Classification Code.

Table 3.4.2-15
Emission Factors For Metal Emissions From Drum Mix Hot Mix Asphalt Plants[a]

Process	Pollutant	Emission factor		Emission Factor Rating	Ref. Nos.
		kg/Mg	lb/ton		
Dryer[b] (SCC 3-05-002-05)	Arsenic	5.5×10^{-7}	1.1×10^{-6}	D	25,35
	Barium	2.4×10^{-6}	4.8×10^{-6}	D	25
	Cadmium	2.2×10^{-7}	4.4×10^{-7}	D	25,35
	Chromium	6.0×10^{-6}	1.2×10^{-5}	D	25
	Copper	3.1×10^{-6}	6.1×10^{-6}	D	25
	Lead	1.7×10^{-6}	3.3×10^{-6}	D	25,35
	Manganese	5.5×10^{-6}	1.1×10^{-5}	D	25
	Mercury	3.7×10^{-9}	7.3×10^{-9}	D	35
	Nickel	7.5×10^{-6}	1.5×10^{-5}	D	25
	Phosphorus	2.8×10^{-5}	5.5×10^{-5}	D	25
	Silver	7.0×10^{-7}	1.4×10^{-6}	D	25
	Zinc	2.1×10^{-5}	4.2×10^{-5}	D	25,35

[a]Emission factor in kg/Mg and lb/ton of hot mix asphalt produced. Emissions controlled by a fabric filter. SCC = Source Classification Code.
[b]Feed material includes RAP.

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3.5.1 Crushed Stone Processing

3.5.1 Crushed Stone Processing

Source of Emissions Data

The following information was obtained from:

U.S. Environmental Protection Agency. 1995. *Compilation of Air Pollutant Emission Factors, Volume I: Stationary Point and Area Sources* (Fifth Edition–DRAFT). Section 11.19.2.

Estimating Emissions

General Description.[1-2] Major rock types processed by the rock and crushed stone industry include limestone, granite, dolomite, traprock, sandstone, quartz, and quartzite. Minor types include calcareous marl, marble, shell, and slate. Industry classifications vary considerably and, in many cases, do not reflect actual geological definitions.

Rock and crushed stone products generally are loosened by drilling and blasting, then are loaded by power shovel or front-end loader into large haul trucks that transport the material to the processing operations. Techniques used for extraction vary with the nature and location of the deposit. Processing operations may include crushing, screening, size classification, material handling, and storage operations. All of these processes can be significant sources of PM and PM_{10} emissions if uncontrolled.

Quarried stone normally is delivered to the processing plant by truck and is dumped into a hoppered feeder, usually a vibrating grizzly type, or onto screens, as illustrated in Figure 3.5.1-1. The feeder or screens separate large boulders from finer rocks that do not require primary crushing, thus reducing the load to the primary crusher. Jaw, impactor, or gyratory crushers are usually used for initial reduction. The crusher product, normally 7.5 to 30 centimeters (3 to 12 inches) in diameter, and the grizzly throughs (undersize material) are discharged onto a belt conveyor and usually are conveyed to a surge pile for temporary storage, or are sold as coarse aggregates.

The stone from the surge pile is conveyed to a vibrating inclined screen called the scalping screen. This unit separates oversized rock from the smaller stone. The undersize material from the scalping screen is considered to be a product stream and is transported to a storage pile and sold as base material. The stone that is too large to pass through the top deck of the scalping screen is processed in the secondary crusher. Cone crushers are commonly used for secondary crushing (although impact crushers are sometimes used), which typically reduces material to about 2.5 to 10 centimeters (1 to 4 inches). The material (throughs) from the second level of the screen bypasses the secondary crusher because it is sufficiently small for the last crushing step. The output from the secondary crusher and the throughs from the secondary screen are transported by conveyor to the tertiary circuit, which includes a sizing screen and a tertiary crusher.

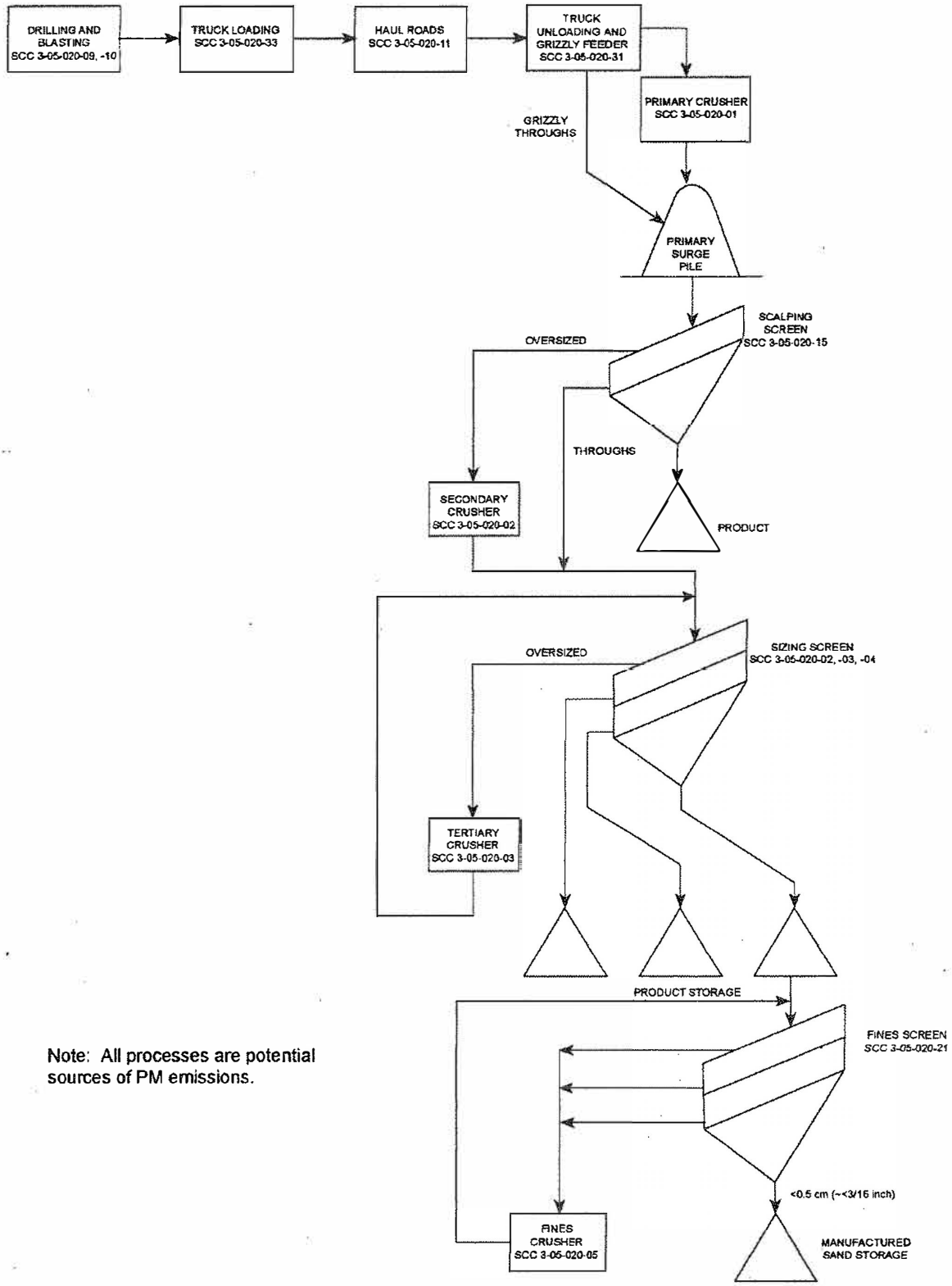

Figure 3.5.1-1. Typical stone processing plant.[2]
(SCC = Source Classification Code.)

Tertiary crushing is usually performed using cone crushers or other types of impactor crushers. Oversize material from the top deck of the sizing screen is fed to the tertiary crusher. The tertiary crusher output, which is typically about 0.50 to 2.5 centimeters (3/16th to 1 inch), is returned to the sizing screen. Various product streams with different size gradations are separated in the screening operation. The products are conveyed or trucked directly to finished product bins, open area stockpiles, or to other processing systems such as washing, air separators, and screens and classifiers (for the production of manufactured sand).

Some stone crushing plants produce manufactured sand. This is a small-sized rock product with a maximum size of 0.50 centimeter (3/16 inch). Crushed stone from the tertiary sizing screen is sized in a vibrating inclined screen (fines screen) with relatively small mesh sizes. Oversized material is processed in a cone crusher or a hammermill (fines crusher) adjusted to produce small diameter material. The output is then returned to the fines screen for resizing.

In certain cases, stone washing is required to meet particular end product specifications or demands, as with concrete aggregate processing. Crushed and broken stone normally is not milled but is screened and shipped to the consumer after secondary or tertiary crushing.

Emission Factor Data.[1-4,7-8] Emissions of PM and PM_{10} occur from a number of operations in stone quarrying and processing. A substantial portion of these emissions consists of heavy particles that may settle out within the plant. As in other operations, crushed stone emission sources may be categorized as either process sources or fugitive dust sources. Process sources include those for which emissions are amenable to capture and subsequent control. Fugitive dust sources generally involve the reentrainment of settled dust by wind or machine movement. Emissions from process sources should be considered fugitive unless the sources are vented to a baghouse or are contained in an enclosure with a forced-air vent or stack. Factors affecting emissions from either source category include the stone size distribution and surface moisture content of the stone processed; the process throughput rate; the type of equipment and operating practices used; and topographical and climatic factors.

Of geographic and seasonal factors, the primary variables affecting uncontrolled PM emissions are wind and material moisture content. Wind parameters vary with geographical location, season, and weather. It can be expected that the level of emissions from unenclosed sources (principally fugitive dust sources) will be greater during periods of high winds. The material moisture content also varies with geographic location, season, and weather. Therefore, the levels of uncontrolled emissions from both process emission sources and fugitive dust sources generally will be greater in arid regions of the country than in temperate ones, and greater during the summer months because of a higher evaporation rate.

The moisture content of the material processed can have a substantial effect on emissions. This effect is evident throughout the processing operations. Surface wetness causes fine particles to agglomerate on, or to adhere to, the faces of larger stones, with a resulting dust suppression effect. However, as new fine particles are created by crushing and attrition, and

as the moisture content is reduced by evaporation, this suppressive effect diminishes and may disappear. Plants that use wet suppression systems (spray nozzles) to maintain relatively high material moisture contents can effectively control PM emissions throughout the process. Depending on the geographic and climatic conditions, the moisture content of mined rock may range from nearly zero to several percent. Because moisture content is usually expressed on a basis of overall weight percent, the actual moisture amount per unit area will vary with the size of the rock being handled. On a constant mass-fraction basis, the per-unit area moisture content varies inversely with the diameter of the rock. Therefore, the suppressive effect of the moisture depends on both the absolute mass water content and the size of the rock product. Typically, wet material contains 1.5 to 4 percent water or more.

A variety of material, equipment, and operating factors can influence emissions from crushing. These factors include stone type, feed size and distribution, moisture content, throughput rate, crusher type, size reduction ratio, and fines content. Insufficient data are available to present a matrix of rock crushing emission factors detailing the above classifications and variables. Available data indicate that PM_{10} emissions from limestone and granite processing operations are similar. Therefore, the emission factors developed from the emission data gathered at limestone and granite processing facilities are considered to be representative of typical crushed stone processing operations. Emission factors for filterable PM and PM_{10} emissions from crushed stone processing operations are presented in Tables 3.5.1-1 (metric units) and -2 (English units).

Emission factor estimates for stone quarry blasting operations are not presented here because of the sparsity and unreliability of available test data. While a procedure for estimating blasting emissions is presented in *AP-42*, Fourth Edition, Section 11.24, "Western Surface Coal Mines," that procedure should not be applied to stone quarries because of dissimilarities in blasting techniques, material blasted, and size of blast areas. Milling of fines is not included in this section as this operation is normally associated with nonconstruction aggregate end uses and will be covered elsewhere when information is adequate. Emission factors for fugitive dust sources, including unpaved and paved roads (see Sections 3.2.1 and 3.2.2 of this document), materials handling and transfer, and wind erosion of storage piles (Section 13.2.4 of *AP-42*, Fifth Edition), can be determined using the predictive emission factor equations.

Emission Calculations. The particulate emissions from stone processing facilities are estimated by summing the emissions from all individual processing operations. The total emissions can be estimated with the following equation:

$$E = (EF_{drilling} \cdot T_{drilling}) + (EF_{screening} \cdot T_{screening}) + (EF_{crushing} \cdot T_{crushing}) + (EF_{loading} \cdot T_{loading}) + \ldots$$

where E = Particulate daily emissions, kg/day (lb/day)
EF = Emission factor, kg/Mg (lb/ton)
T = Amount of material throughput (for each operation) in 1 day, Mg/day (tons/day)

An example calculation for determining PM emissions from a stone crushing plant is given below.

Example

A paved roadway is proposed to improve access to a wilderness area in northern California. Stone, needed for the construction of the roadway, is available from a quarry near the proposed alignment. To reduce the cost of transporting the raw materials to a processing plant, a temporary stone processing facility will be built and operated at the quarry. It is estimated that 100 tons per day of crushed stone are needed for the construction of the roadway. Assume that the moisture content of the material is less than 1.5 percent (uncontrolled). Estimate PM_{10} emissions from stone processing for the following operations and the indicated throughput for each operation:

Drilling and blasting (100 tons per day)
Screening (100 tons per day)
Primary crushing (90 tons per day)
Conveyor from primary circuit to scalping screen (100 tons per day)
Scalping screen (100 tons per day)
Secondary crusher (70 tons per day)
Conveyor from secondary crusher to sizing screen (70 tons per day)
Sizing screen (90 tons per day)
Tertiary crusher (20 tons per day)
Conveyor from tertiary crusher to sizing screen (20 tons per day)
Truck loading (100 tons per day)

The following equation shows the emission factor and throughput for each process in the order listed above. Though the calculation can be simplified, the equation is shown in detail for demonstration purposes.

Please note: Refer to *AP-42*, Section 13.2.4, "Aggregate Handling and Storage Piles," for emission factors of additional processes related, but not specific to stone processing.

$$E = \left(8.0x10^{-5}\frac{lb}{ton} \cdot 100\frac{tons}{day}\right) + \left(0.015\frac{lb}{ton} \cdot 100\frac{tons}{day}\right) + \left(0.00\frac{lb}{ton} \cdot 90\frac{tons}{day}\right)$$

$$+ \left(0.0014\frac{lb}{ton} \cdot 100\frac{tons}{day}\right) + \left(0.015\frac{lb}{ton} \cdot 100\frac{tons}{day}\right) + \left(0.0024\frac{lb}{ton} \cdot 70\frac{tons}{day}\right)$$

$$+ \left(0.0014\frac{lb}{ton} \cdot 70\frac{tons}{day}\right) + \left(0.015\frac{lb}{ton} \cdot 90\frac{tons}{day}\right) + \left(0.0024\frac{lb}{ton} \cdot 20\frac{tons}{day}\right)$$

$$+ \left(0.0014\frac{lb}{ton} \cdot 20\frac{tons}{day}\right) + \left(0.00010\frac{lb}{ton} \cdot 100\frac{tons}{day}\right)$$

$$= 4.85\frac{lb}{day} \text{ of } PM_{10}$$

Mitigation Techniques

Uncontrolled construction aggregate processing can produce nuisance problems and have an effect upon attainment of ambient particulate standards. As described in the Emission Factor Data section above, wet suppression systems (spray nozzles) are an effective method for controlling particulate emissions. Wet suppression is effective for controlling emissions from crushing and grinding, conveyors, loading and unloading, and screening operations. These wet processes do not generate appreciable particulate emissions.

Emissions from drilling and blasting, loading, and screening operations can also be reduced if these processes are conducted during the winter months or during periods of calm winds and cool temperatures. Covering conveyors and screening equipment is a common method of controlling emissions from these stone processing operations. Emissions from loading and unloading can be effectively controlled using methods to reduce freefall distances (i.e., telescopic chutes, stone ladders, hinged boom stacker conveyors).

Table 3.5.1-1
Emission Factors For Crushed Stone Processing Operations[a]
(Metric Units)

Source[b]	Filterable PM[c]	Emission Factor Rating	PM_{10}	Emission Factor Rating
Screening (SCC 3-05-020-02,-03)	0.073[d]	E	0.0076[e]	C
Screening with wet suppression (SCC 3-05-020-02,-03)	0.0042[d]	E	0.00042[e]	C
Primary crushing (SCC 3-05-020-01)	0.00035[f]	E	ND	
Secondary crushing (SCC 3-05-020-02)	[g]	E	[g]	E
Tertiary crushing (SCC 3-05-020-03)	0.018[h]	E	0.0012[j]	C
Primary crushing with wet suppression (SCC 3-05-020-01)	ND		ND	
Secondary crushing with wet suppression (SCC 3-05-020-02)	[g]	E	[g]	E
Tertiary crushing with wet suppression (SCC 3-05-020-03)	0.00079[h]	E	0.00029[j]	C
Fines crushing[k] (SCC 3-05-020-05)	0.36	E	0.0075	E
Fines crushing with wet suppression[k] (SCC 3-05-020-05)	0.067	E	0.0010	E
Fines screening[k] (SCC 3-05-020-21)	0.15	E	0.036	E
Fines screening with wet suppression[k] (SCC 3-05-020-21)	0.0018	E	0.0011	E
Conveyor transfer point[m] (SCC 3-05-020-06)	0.013	E	0.00072	D
Conveyor transfer point with wet suppression[m] (SCC 3-05-020-06)	6.9×10^{-5}	E	2.4×10^{-5}	D
Wet drilling: unfragmented stone[n] (SCC 3-05-020-10)	ND		4.0×10^{-5}	E
Truck loading: fragmented stone[n] (SCC 3-05-020-31)	ND		8.0×10^{-6}	E
Truck loading–conveyor: crushed stone[p] (SCC 3-05-020-32)	ND		5.0×10^{-5}	E

Table 3.5.1-1
Emission Factors For Crushed Stone Processing Operations[a]
(Metric Units)

Source[b]	Filterable PM[c]	Emission Factor Rating	PM_{10}	Emission Factor Rating

[a]Emission factors represent uncontrolled emissions unless noted. Emission factors in kg/Mg of material throughput. SSC = Source Classification Code. ND = no data available.
[b]Sources controlled with wet suppression maintain a material moisture content ≥ 1.5 percent. Sources that process material with a moisture content of <1.5 percent are considered to be uncontrolled.
[c]Based on information provided in *AP-42* Section 13.2.1, TSP emissions can be estimated by multiplying the filterable PM emission factor by 0.80. However, no data are available to support this approximation, and the calculated TSP emission factors are not suitable for rating or inclusion in *AP-42*.
[d]References 6, 11, 15-16.
[e]References 9, 11, 15-16.
[f]Reference 1.
[g]No data available, but emission factors for tertiary crushing can be used as an upper limit for secondary crushing.
[h]References 11, 15-16.
[j]References 10-11, 15-16.
[k]Reference 12.
[m]References 13-14.
[n]Reference 3.
[p]Reference 4.

Table 3.5.1-2
Emission Factors For Crushed Stone Processing Operations[a]
(English Units)

Source[b]	Filterable PM[c]	Emission Factor Rating	PM_{10}	Emission Factor Rating
Screening (SCC 3-05-020-02,-03)	0.15[d]	E	0.015[e]	C
Screening with wet suppression (SCC 3-05-020-02,-03)	0.0084[d]	E	0.00084[e]	C
Primary crushing (SCC 3-05-020-01)	0.00070[f]	E	ND	
Secondary crushing (SCC 3-05-020-02)	[g]	E	[g]	E
Tertiary crushing (SCC 3-05-020-03)	0.036[h]	E	0.0024[j]	C
Primary crushing with wet suppression (SCC 3-05-020-01)	ND		ND	
Secondary crushing with wet suppression (SCC 3-05-020-02)	[g]	E	[g]	E
Tertiary crushing with wet suppression (SCC 3-05-020-03)	0.0016[h]	E	0.00059[j]	C
Fines crushing[k] (SCC 3-05-020-05)	0.72	E	0.015	E
Fines crushing with wet suppression[k] (SCC 3-05-020-05)	0.13	E	0.0020	E
Fines screening[k] (SCC 3-05-020-21)	0.30	E	0.071	E
Fines screening with wet suppression[k] (SCC 3-05-020-21)	0.0036	E	0.0021	E
Conveyor transfer point[m] (SCC 3-05-020-06)	0.026	E	0.0014	E
Conveyor transfer point with wet suppression[m] (SCC3-05-020-06)	0.00014	E	4.8×10^{-5}	D
Wet drilling: unfragmented stone[n] (SCC 3-05-020-10)	ND		8.0×10^{-5}	E
Truck unloading: fragmented stone[n] (SCC 3-05-020-31)	ND		1.6×10^{-5}	E
Truck loading–conveyor: crushed stone[p] (SCC 3-05-020-32)	ND		0.00010	E

Table 3.5.1-2
Emission Factors For Crushed Stone Processing Operations[a]
(English Units)

Source[b]	Filterable PM[c]	Emission Factor Rating	PM_{10}	Emission Factor Rating

[a]Emission factors represent uncontrolled emissions unless noted. Emission factors in lb/ton of material throughput. SCC = Source Classification Code. ND = no data available.
[b]Sources controlled with wet suppression maintain a material moisture content ≥ 1.5 percent. Sources that process material with a moisture content of <1.5 percent are considered to be uncontrolled.
[c]Based on information provided in *AP-42* Section 13.2.1, TSP emissions can be estimated by multiplying the filterable PM emission factor by 0.80. However, no data are available to support this approximation, and the calculated TSP emission factors are not suitable for rating or inclusion in *AP-42*.
[d]References 6, 11, 15-16.
[e]References 9, 11, 15-16.
[f]Reference 1.
[g]No data available, but emission factors for tertiary crushing can be used as an upper limit for secondary crushing.
[h]References 11, 15-16.
[j]References 10-11, 15-16.
[k]Reference 12.
[m]References 13-14.
[n]Reference 3.
[p]Reference 4.

References

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10. J. Richards, T. Brozell, and W. Kirk. *PM_{10} Emission Factors for a Stone Crushing Plant Tertiary Crusher*, EPA Contract No. 68-D1-0055, Task 2.84, U.S. Environmental Protection Agency, Research Triangle Park, NC, February 1992.

11. W. Kirk, T. Brozell, and J. Richards. *PM_{10} Emission Factors for a Stone Crushing Plant Deister Vibrating Screen and Crusher*, National Stone Association, Washington DC, December 1992.

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13. T. Brozell. *PM_{10} Emission Factors for Two Transfer Points at a Granite Stone Crushing Plant*, EPA Contract No. 68-D0-0122, U.S. Environmental Protection Agency, Research Triangle Park, NC, January 1994.

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3.5.2 Sand and Gravel Processing

3.5.2 Sand and Gravel Processing

Source of Emissions Data

The following information was obtained from:

U.S. Environmental Protection Agency. 1985 and ff. *Compilation of Air Pollutant Emission Factors, Volume I: Stationary Point and Area Sources* (Fourth Edition). Section 8.19.1.

Estimating Emissions

General Description.[1-3] Deposits of sand and gravel, the consolidated granular materials resulting from the natural disintegration of rock or stone, are generally found in near-surface alluvial deposits and in subterranean and subaqueous beds. Sand and gravel are products of the weathering of rocks and unconsolidated or poorly consolidated materials and consist of siliceous and calcareous components. Such deposits are common throughout the country.

Depending upon the location of the deposit, the materials are excavated with power shovels, draglines, front end loaders, suction dredge pumps or other apparatus. In rare situations, light charge blasting is done to loosen the deposit. The materials are transported to the processing plant by suction pump, earth mover, barge, truck, or other means. The processing of sand and gravel for a specific market involves the use of different combinations of washers, screens and classifiers to segregate particle sizes; crushers to reduce oversize material; and storage and loading facilities. Crushing operations, when used, are designed to reduce production of fines, which often must be removed by washing. Therefore, crusher characteristics, size reduction ratios and throughput, among other factors, are selected to obtain the desired product size distribution.

In many sand and gravel plants, a substantial portion of the initial feed bypasses any crushing operations. Some plants do no crushing at all. After initial screening, material is conveyed to a portion of the plant called the wet processing section, where wet screening and silt removal are conducted to produce washed sand and gravel. Negligible air emissions are expected from the wet portions of a sand and gravel plant.

Industrial sand processing is similar to that of construction sand, insofar as the initial stages of crushing and screening are concerned. Industrial sand has a high (90 to 99 percent) quartz or silica content and is frequently obtained from quartz rich deposits of sand or sandstone. At some plants, after initial crushing and screening, a portion of the sand may be diverted to construction sand use. Industrial sand processes not associated with construction sand include wet milling, scrubbing, desliming, flotation, drying, air classification, and cracking of sand grains to form very fine sand products.

Emission Factor Data.[1] Dust emissions can occur from many operations at sand and gravel processing plants, such as conveying, screening, crushing, and storing operations. Generally,

these materials are wet or moist when handled, and process emissions are often negligible. A substantial portion of these emissions may consist of heavy particles that settle out within the plant. Emission factors (for process or fugitive dust sources) from sand and gravel processing plants are shown in Table 3.5.2-1. (If processing is dry, expected emissions could be similar to those given in Section 3.5.1 of this document, "Crushed Stone Processing.")

Emission factors for crushing wet materials can be applied directly or on a dry basis, with a control efficiency credit being given for use of wet materials (defined as 1.5 to 4.0 percent moisture content or greater) or wet suppression. The latter approach is more consistent with current practice.

The single valued fugitive dust emission factors given in Table 3.5.2-1 may be used for an approximation when no other information exists. Empirically derived emission factor equations presented in Section 3.2 of this document are preferred and should be used when possible. Each of those equations has been developed for a single source operation or dust generating mechanism that crosses industry lines, such as vehicle traffic on unpaved roads. The predictive equation explains much of the observed variance in measured emission factors by relating emissions to the differing source variables. These variables may be grouped as follows:

- Measures of source activity or expended energy (for example, feed rate, or speed and weight of a vehicle traveling on an unpaved road)
- Properties of the material being disturbed (for example, moisture content, or content of suspendable fines in the material)
- Climate (for example, number of precipitation-free days per year, when emissions tend to a maximum)

Because predictive equations allow for emission factor adjustment to specific conditions, they should be used instead of the factors given in Table 3.5.2-1 whenever emission estimates are needed for sources in a specific sand and gravel processing facility. However, the generally higher quality ratings assigned to these equations are applicable only if (1) reliable values of correction parameters have been determined for the specific sources of interest, and (2) the correction parameter values lie within the ranges found in developing the equations. Section 13.2.4 of *AP-42*, Fifth Edition, lists measured properties of aggregate materials used in operations similar to the sand and gravel industry, and these properties can be used to approximate correction parameter values for use in the predictive emission factor equations, in the event that site-specific values are not available. Use of mean correction parameter values from Section 3.2 reduces the quality ratings of the emission factor equations by at least one level.

Emission Calculations. The particulate emissions from sand and gravel processing facilities are estimated using the following equation:

$$E = \sum (EF \cdot T)_{each\ process}$$

where E = Particulate daily emissions, kg/day (lb/day)
EF = Emission factor, kg/Mg (lb/ton) or kg/hectare/day (lb/acre/day)
T = Amount of material throughput in one day, Mg/day (tons/day) or hectares (acres)

An example calculation for determining PM emissions from a sand and gravel processing plant is given below:

Example

The paved roadway proposed to improve access to a wilderness area in northern California (see Section 3.5.1, "Crushed Stone Processing") requires sand to stabilize the gravel used in the roadway's construction. The sand will be trucked to the stone processing facility at the construction site because it is less expensive than processing the sand from stone. It is estimated that 50 tons per day of sand are needed for the construction of the roadway. Using the emission factors from Table 3.5.2-1, estimate PM_{10} emissions from the unloading and storage of sand. Assume that the storage pile is disturbed frequently and covers an area of 225 square feet, and that the moisture content of the material is less than 1.5 percent (uncontrolled).

The following equation shows the emission factor and throughput for each process.

$$E = \left(0.0024 \frac{lb}{ton} \cdot 50 \frac{tons}{day}\right) + \left(6.3 \frac{lb}{acre \cdot ton} \cdot 0.005165\ acre\right)$$

$$= 0.15 \frac{lb}{day}\ of\ PM_{10}$$

Mitigation Techniques

Since emissions from sand and gravel operations usually are in the form of fugitive dust, control techniques applicable to fugitive dust sources are appropriate. Some successful control techniques used for haul roads are application of dust suppressants, paving, route modifications, and soil stabilization; for conveyors, covering and wet suppression; for storage

piles, wet dust suppression, windbreaks, enclosure, and soil stabilizers; and for conveyor and batch transfer points (loading and unloading, etc.), wet suppression and various methods to reduce freefall distances (for example, telescopic chutes, stone ladders, and hinged boom stacker conveyors); for screening and other size classification, covering and wet suppression.

Wet suppression techniques include application of water, chemicals, and/or foam, usually at crusher or conveyor feed and/or discharge points. Such spray systems at transfer points and on material handling operations have been estimated to reduce emissions 70 to 95 percent.[7] Spray systems can also reduce loading and wind erosion emissions from storage piles of various materials 80 to 90 percent.[8] Control efficiencies depend upon local climatic conditions, source properties, and the duration of control effectiveness. Wet suppression has a carryover effect downstream of the point of application of water or other wetting agents, as long as the surface moisture content is high enough to cause the fines to adhere to the larger rock particles.

Table 3.5.2-1
Uncontrolled Particulate Emission Factors
For Sand and Gravel Processing Plants[a]

Uncontrolled Operation	Emissions by Particle Size Range (aerodynamic diameter)[b]				Emission Factor Rating
	Total Particulate	TSP (< 30 um)	PM10 (< 10 um)	Units	
Process Sources[c]					
Primary or secondary crushing (wet)	NA	0.009 (0.018)	NA	kg/Mg (lb/ton)	D
Open Dust Sources[c]					
Screening[d]					
Flat screens (dry product)	NA	0.08 (0.16)	0.06 (0.12)	kg/Mg (lb/ton)	C
Continuous drop[c]					
Transfer station	0.014 (0.029)	NA	NA	kg/Mg (lb/ton)	E
Pile formation-stacker	NA	0.065 (0.13)	0.03 (0.06)[e]	kg/Mg (lb/ton)	E
Batch drop[c]					
Bulk loading	0.12 (0.024)	0.028 (0.056)[f]	0.0012 (00024)[f]	kg/Mg (lb/ton)	E
Active storage piles[g]					
Active day	NA	14.8 (13.2)	7.1 (6.3)[e]	kg/hectare/day[h] (lb/acre/day)	D
Inactive day (wind erosion only)	NA	3.9 (3.5)	1.9 (1.7)[e]	kg/hectare/day[h] (lb/acre/day)	D
Unpaved haul roads					
Wet materials	[i]	[i]	[i]		D

[a]NA = not available. TSP = total suspended particulate. Predictive emission factor equations, which generally provide more accurate estimates of emissions under specific conditions, are presented in the "Fugitive Dust Emissions" section of *AP-42*. Factors for open dust sources are not necessarily representative of the entire industry or of a "typical" situation.

[b]Total particulate is airborne particles of all sizes in the source plume. TSP is what is measured by a standard high volume sampler (see the "Fugitive Dust Emissions" section of *AP-42*).

[c]References 5-9.

[d]References 4-5. For completely wet operations, emissions are likely to be negligible.

[e]Extrapolation of data, using k factors for appropriate operation from the "Fugitive Dust Emissions" section of *AP-42*.

[f]For physical, not aerodynamic, diameter.

[g]Reference 6. Includes the following distinct source operations in the storage cycle: (1) loading of aggregate onto storage piles (batch or continuous drop operations), (2) equipment traffic in storage areas, (3) wind erosion of pile (batch or continuous drop operations). Assumes 8 to 12 hours of activity/24 hours.

[h]Kg/hectare (lb/acre) of storage/day (includes areas among piles).

[i]See the "Fugitive Dust Emissions" section of *AP-42* for empirical equations.

References

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9. *Fugitive Dust Assessment at Rock and Sand Facilities in the South Coast Air Basin*, Southern California Rock Products Association and Southern California Ready Mix Concrete Association, P.E.S., Santa Monica, CA, November 1979.

3.5.3 Ore Crushing and Grinding

3.5.3 Ore Crushing and Grinding

General Source Description[1]

While there are a great number of differences in the configuration and equipment used in various surface mines, there are also many similarities between the fugitive dust operations whether the ore is coal, iron, non-ferrous, uranium, phosphate or rock[2]. Many emission factors were developed from measurements at western surface coal mines. The following section deals with leadbearing ore but could be applied to other types of ore.

Leadbearing ore is mined from underground or open pit mines. After extraction, the ore is processed by crushing, screening and milling. Domestic lead mine production for 1991 totaled 480,000 megagrams (530,000 tons) of lead in ore concentrates, a decrease of some 15,000 megagrams (16,500 tons) from 1990 production.

Except for mines in Missouri, lead ore is closely interrelated with zinc and silver. Lead ores from Missouri mines are primarily associated with zinc and copper. Average grades of metal from Missouri mines have been reported as high as 12.2 percent lead, 1 percent zinc, and 0.6 percent copper. Due to ore body formations, lead and zinc ores are normally deep mined (underground), whereas copper ores are mined in open pits. Lead, zinc, copper, and silver are usually found together (in varying percentages) in combination with sulfur and/or oxygen.

Process Description[3,6-8]

In underground mines the ore is disintegrated by percussive drilling machines, processed through a primary crusher, and then conveyed to the surface. In open pit mines, ore and gangue are loosened and pulverized by explosives, scooped up by mechanical equipment, and transported to the concentrator. A trend toward increased mechanical excavation as a substitute for standard cyclic mine development, such as drill-and-blast and surface shovel-and-truck routines has surfaced as an element common to most metal mine cost-lowering techniques.

Standard crushers, screens, and rod and ball mills classify and reduce the ore to powders in the 65 to 325 mesh range. The finely divided particles are separated from the gangue and are concentrated in a liquid medium by gravity and/or selective flotation, then cleaned, thickened and filtered. The concentrate is dried prior to shipment to the smelter.

Controls and Emission Factors[3-5,9]

Lead emissions are largely fugitive and are caused by drilling, loading, conveying, screening, unloading, crushing, and grinding. The primary means of control are good mining techniques and equipment maintenance. These practices include enclosing the truck loading operation, wetting or covering truck loads and stored concentrates, paving the road from mine to concentrator, sprinkling the unloading area, and preventing leaks in the crushing and grinding enclosures. Cyclones and fabric filters can be used in the milling operations.

Particulate and lead emission factors for lead ore crushing and materials handling operations are given in Tables 3.5.3-1 and 3.5.3-2. Additionally, the VOC/PM Speciation Database (SPECIATE) indicates that the following CAA Title III hazardous air pollutants (HAPs) emissions. All of these metals are listed in CAA Title III as hazardous air pollutants (HAPs). Emissions of metals are associated with crushing and grinding lead ores. These metals include chromium, manganese, nickel, arsenic, selenium, cadmium, antimony, and mercury, as well as lead in process.

Table 3.5.3-1 (Metric Units)
Emission Factors for Ore Crushing and Grinding

Type of ore and lead content (wt%)		Particulate Emission Factor[a]	Emission Factor Rating	Lead Emission Factor[b]	Emission Factor Rating
Lead[c] (SCC 3-03-031-01)	5.1	3.0	B	0.15	B
Zinc[d] (SCC 3-03-031-02)	0.2	3.0	B	0.006	B
Copper[e] (SCC 3-03-031-03)	0.2	3.2	B	0.006	B
Lead-Zinc[f] (SCC 3-03-031-04)	2.0	3.0	B	0.06	B
Copper-Lead[g] (SCC 3-03-031-05)	2.0	3.2	B	0.06	B
Copper-Zinc[h] (SCC 3-03-031-06)	0.2	3.2	B	0.006	B
Copper-Lead-Zinc[i] (SCC 3-03-031-07)	2.0	3.2	B	0.06	B

[a]Reference 2. Units are expressed as kg of pollutant/Mg ore processed.
[b]Reference 2,3,5,7.
[c]Refer to Section 12.6.
[d]Characteristic of some mines in Colorado.
[e]Characteristic of some mines in Alaska, Idaho, and New York.
[f]Characteristic of Arizona mines.
[g]Characteristic of some mines in Missouri, Idaho, Colorado, and Montana.
[h]Characteristic of some mines in Missouri.
[i]Does not appear in ore characterization of the top 25 domestic lead producing mines.

Table 3.5.3-2 (English Units)
Emission Factors for Ore Crushing and Grinding

Type of ore and lead content (wt%)		Particulate Emission Factor[a]	Emission Factor Rating	Lead Emission Factor[b]	Emission Factor Rating
Lead[c] (SCC 3-03-031-01)	5.1	6.0	B	0.30	B
Zinc[d] (SCC 3-03-031-02)	0.2	6.0	B	0.012	B
Copper[e] (SCC 3-03-031-03)	0.2	6.4	B	0.012	B
Lead-Zinc[f] (SCC 3-03-031-04)	2.0	6.0	B	0.12	B
Copper-Lead[g] (SCC 3-03-031-05)	2.0	6.4	B	0.12	B
Copper-Zinc[h] (SCC 3-03-031-06)	0.2	6.4	B	0.012	B
Copper-Lead-Zinc[i] (SCC 3-03-031-07)	2.0	6.4	B	0.12	B

[a]Reference 3. Units are expressed as lb of pollutant/ton ore processed.
[b]Reference 3,4,6,8.
[c]Refer to Section ------.
[d]Characteristic of some mines in Colorado.
[e]Characteristic of some mines in Alaska, Idaho, and New York.
[f]Characteristic of Arizona mines.
[g]Characteristic of some mines in Missouri, Idaho, Colorado, and Montana.
[h]Characteristic of some mines in Missouri.
[i]Does not appear in ore characterization of the top 25 domestic lead producing mines.

Before calculating the particulate matter(PM) or lead emissions from ore crushing and grinding, the type of ore and its lead content by weight must be determined. Then the appropriate emission factor from Table 3.5.3-2 can be applied.

Example

Estimate the particulate emissions from primary coal crushing which has a simple cyclone to control particulate emissions. Assume:

- 100 ton/day of coal is crushed
- 65.3% control efficiency

$$\textit{Total PM (primary crushing)} = \left(\frac{0.02\ lb\ PM}{tons\ of\ coal}\right)\left(\frac{100\ tons\ coal\ crushed}{day}\right)(0.653)$$

$$= \frac{1.3\ kb\ PM}{day}\ \textit{(primary crushing)}$$

Example

Estimate particulate and lead emissions from a lead-zinc grinding material handling operation which processes 50 Mg lead-zinc ore a day. Assume lead content is 2% by weight.

$$\textit{Total PM} = \left(\frac{3.0\ kg\ PM}{Mg\ ore}\right)\left(\frac{50\ Mg\ ore}{day}\right)$$

$$= \frac{150\ Mg\ PM}{day}$$

$$\textit{Total Pb} = \left(\frac{0.06\ kg\ Pb}{Mg\ ore}\right)\left(\frac{50\ Mg\ ore}{day}\right)$$

$$= \frac{3\ kg\ Pb}{day}$$

References

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2. *Fugitive Dust Emission Factors for the Mining Industry.* American Mining Congress. July, 1982.

3. *Control Techniques For Lead Air Emissions.* EPA-450/2-77-012A. U. S. Environmental Protection Agency. Research Triangle Park, NC. December 1977.

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9. *VOC/PM Speciation Data System.* Radian Corporation. EPA Contract No. 68-02-4286. November 1990.

3.6.1 Well Farm Emissions

3.6.1 Well Field Emissions

Source of Emissions Data

The following information was obtained from:

Air and Waste Management Association, 1992. *Air Pollution Engineering Manual (AP-40)*, Chapter 17.

Estimating Emissions

General Description. The exploration and production of oil and gas involves the recovery of natural gas and crude oil from underground reservoirs. Exploration and production activities include the following:

- Exploration and well-site preparation
- Drilling
- Crude oil and gas processing
- Enhanced recovery

Exploration and well-site preparation activities do not contribute significantly to air emissions; therefore, these activities will not be discussed. This section will describe in detail those activities that are more significant sources of emissions: drilling, processing, and recovery operations.

Drilling Operations. Drilling operations include activities necessary to bore through the earth's crust to access crude oil and natural gas resources. During drilling operations, specially formulated muds are circulated through the hole to remove cuttings from around the drill bit, to provide lubrication for the drill string, to protect the walls of the hole, and to control down-hole pressure. Energy to rotate the drill bit, hoist the drill string, and circulate the mud are provided by internal-combustion (IC) engines or portable well-drilling equipment. This equipment is described in Sections 3.3.3 and 3.3.1 of this document, respectively.

Cuttings are separated from the mud at the well surface as the mud is passed through shale shakers, desanders, desilters, and degassers.[1] The mud flows to a tank for recycling, and the cuttings that may be contaminated with hydrocarbons are pumped to a waste pit for disposal.

Once a well has been completed and is producing crude oil or natural gas, an arrangement of high-pressure valves termed a "Christmas tree" is installed to control production. As the well ages, a pump may be needed to help bring product to the well surface. Pumping units are typically powered by electric motors but are sometimes powered by IC engines.

Crude Oil and Gas Processing. The overall objective of the production facility is to prepare the oil and gas for pipeline transport. The oil is usually transferred to a pipeline terminal and eventually to a refinery, while the gas may be sold to a pipeline company for further sale or transported directly to a gas plant for additional treatment. A variety of types of process equipment may be required at a production facility, depending on the quality of the wellhead product and whether both oil and gas are produced by the well.

The first processing step employed at many production facilities involves separating the oil, gas, and water produced by the well. The separators provide only one stage of separation, and, in many cases, additional water separation from the oil and gas streams may be required. Water in the oil can form an emulsion. This emulsion is broken using heat in heater treaters or electric energy in devices such as electrostatic coalescers. Cleaned oil flows from the emulsin breakers to crude oil storage tanks, which store the crude oil before it is transferred to the pipeline. The water that is recovered during emulsion breaking is often recycled through skimmers to recover remaining oil, is filtered, and then is stored in water tanks prior to underground injection or other discharge.

Natural gas exiting the first-stage separators is composed primarily of methane, with smaller quantities of ethane, propane, butane, and some natural gasoline. It may also contain such impurities as nitrogen, helium, CO_2, hydrogen sulfide (H_2S), mercaptans, and water. Condensible hydrocarbons are recovered from the gas using absorption, refrigeration, or gas expansion processes.[2] Water is removed by passing the gas through equipment such as glycol dehydrators, where the water is absorbed by the glycol. This water is ultimately vented as steam from the glycol reboiler.

The gas-sweetening and product-separation steps are often conducted at a gas plant that is not located at the oil and gas production facility. To sweeten "sour" natural gas, H_2S and CO_2 are usually scrubbed from the gas using an amine solution in an absorption tower.[3] The acid gas stream may be flared, incinerated, or processed further in a sulfur-recovery facility, and the scrubbed gas stream is further processed to separate products. The majority of gas plants use one of the following four processes to separate the hydrocarbon constituents contained in the natural gas stream.[4]

- Absorption
- Refrigerated absorption
- Refrigeration
- Compression

Refrigerated absorption is the process in widest use. In this process, all hydrocarbons except methane are absorbed by an oil operating at low temperature. The methane is transferred to a gas pipeline company, and the heavier hydrocarbon components are separated from the absorber oil and each other in fractionating columns.[5] After separation, these hydrocarbons are transferred to a refinery for additional processing or, in the case of propane and butane, sold directly to users.

Enhanced Recovery. A number of techniques are used to increase the ultimate production of oil and gas from a reservoir. They include water injection, gas injection with CO, thermal processes, and acid treatment and fracturing. Water injection is the most widely applied of these enhanced recovery techniques. Water recovered with oil and gas from production wells is combined with water pumped from water supply wells and then injected into the oil and gas reservoir. This technique forces oil and gas from the reservoir toward the producing wells. Similarly, gas may be injected into a reservoir to create or strengthen a gas cap, which increases the pressure energy in this type of reservoir.[6]

Thermal processes include the injection of steam or heated water, as well as the in situ burning of a portion of the oil in the reservoir.[7] This technique, which is more common in California than in other states, reduces the viscosity of the oil and improves flow characteristics.

Acid treatment and fracturing are two separate techniques, but both increase production by increasing the porosity or permeability of the underground formations.[8] Acid treatment is effective for carbonate rock formations. Hydrochloric acid is usually used to dissolve the carbonate rock. In fracturing, a sand and fluid suspension is pumped down the well at high pressure to crack open sandstone formations, enabling oil and gas to flow more freely to the producing well.

Emission Factor Data. Available emission factor data for each of the exploration and production activities that produce significant amounts of emissions are described below. Unfortunately, estimates of emission rates are not well developed for the exploration and production of oil and gas. The emission rates and pollutants emitted from these activities vary significantly by geographic location, subsurface composition, and local meteorological conditions. It is recommended that site-specific emission factor data be obtained from professional associations such as the American Petroleum Institute.

Drilling Operations. One source of emissions from drilling operations are IC engines or portable well-drilling equipment that provide energy to rotate the drill bit, hoist the drill string, and circulate the mud. Emissions from stationary IC engines are described in Section 3.3.3 of this document and emissions from portable well-drilling equipment are described in Section 3.3.1.

The cuttings that are separated from the mud are a potential source of emissions because the cuttings may be contaminated with hydrocarbons. The cuttings are disposed of in waste pits that may be open to the atmosphere and therefore the emissions may be uncontrolled. One other potential air emission source during drilling is blowouts. However, this source of emissions is not a common occurrence (less than 0.04 percent of all wells drilled in a 10-year period experienced blowouts).[9]

Pumps may be needed for wells that have been producing crude oil or natural gas for a period of time. This equipment may be powered by electric motors that produce no emissions or IC engines that produce emissions as described in Sections 3.3.1 and 3.3.3 of this document.

Crude Oil and Gas Processing. Air emissions occur from a variety of sources at oil and gas production facilities and gas plants. At oil wells, "casing-head gas" may be vented directly to the atmosphere. Hydrocarbons may also be lost with water vapor that is vented from glycol dehydrators and with amines vented from absorbers at gas plants. Crude oil and water are stored in tanks at production facilities and air emissions occur as a result of working and breathing losses from these tanks. Emissions from liquids stored in tanks are described in Section 3.6.2 of this document. Also, at gas plants, natural gasoline may be stored in tanks at atmospheric pressure, and emissions are expected from these storage tanks. The other hydrocarbon products separated at gas plants are stored in pressure vessels, but fugitive emissions may arise from relief valves on these vessels. Fugitive emissions also may occur from valves, flanges, pumps, and compressors located at both gas plants and production facilities.

In addition to hydrocarbon emissions, criteria pollutants are emitted at gas plants and production facilities where IC engines are used to drive pumps, compressors, and other prime movers. Fired vessels such as heater treaters, which often burn natural gas, are another source of criteria pollutants, as are steam generators. A small number of production facilities and all gas plants operate flares, and these devices are an additional source of criteria air pollutants (e.g., SO_2 emissions during acid gas flaring).

Enhanced Recovery. Pumps are used to inject water and other fluids during water flooding, fracturing, and acid treatment. Air emissions will result if IC engines are used to power these pumps. Also, compressors are used during gas injection, and some of these compressors may be driven by IC engines. Emissions from the IC engines are described in Sections 3.3.1 and 3.3.3 of this document.

Mitigation Techniques

Principal sources of emissions from the exploration and production segment include well casing vents, fired vessels, IC engines, oil and water storage tanks, glycol venting, and fugitive (equipment leak) sources. Control measures for each of these sources of emissions are discussed in the following.

Vent Collection System. Collection systems are used to capture gases discharged from well casings during oil production. The most common disposition of collected gases is to a gas plant or dehydration facility. The collected gases also may be compressed for underground reinjection, used as a fuel for prime movers, or fed to a flare for destruction. Collection systems usually include a knockout pot or other device to remove condensible liquids. The control efficiency of the collection system depends on the capture efficiency and how the collected gas is used or destroyed. For example, flares operate at a destruction efficiency of about 98 percent.[10]

Air-Fuel Controllers. Criteria and hazardous air pollutant emissions from combustion sources can be reduced by the use of these controls. Proper air-to-fuel adjustment and control can reduce emissions of VOCs and particulate matter through more efficient combustion. Precombustion chambers vary the air-to-fuel ratio in states to reduce NO_x emissions. In addition, the low NO_x burners are also used to reduce NO_x formation in combustion. The efficiency of air-to-fuel ratio controllers is estimated to be about 50 percent.

Carbon Filter. Carbon absorption can be used to control organic emissions from vent streams, such as from glycol vents. Organic constituents are absorbed on the active surface sites of the carbon particles. When the carbon capacity to absorb organics is exhausted, the carbon must be disposed of or regenerated. Disposable canisters are sometimes used for low-organic-loading vent streams.

Refrigeration. Low-temperature condensers can be used to recover organic constituents from vent streams. The temperature of the vent stream is reduced to below the dew point of the condensibles. Chilled water, brine, and low-boiling-point gases can be used as coolants. Condenser efficiencies range between 85 percent and 95 percent.[11]

Fixed and Floating Roofs. Fixed and floating roofs tanks are described in Section 3.6.2 of this document.

Inspection and Maintenance. Fugitive emissions due to equipment leaks from pump and compressor seals, valves, flanges, and other equipment connections can be reduced by an active inspection and maintenance program. Leaking equipment is identified during periodic inspections with a vapor-detection device. The leaking equipment is logged on a maintenance schedule and mechanical adjustments (e.g., tightening valve stems, packing) are made to repair the leaks. The efficiency of this control procedure is affected by how often the inspections are conducted. In addition, leakless equipment has been developed to reduce fugitive emission losses from such equipment as valves and pump seals.

References

1. *Industrial Process Profiles for Environmental Use: Chapter 2. Oil and Gas Production Industry*, EPA-600/2-77-023b, U.S. Environmental Protection Agency, Cincinnati, OH, 1977, p. 16.

2. *Industrial Process Profiles for Environmental Use*, p. 34.

3. *SO_2 Emissions in Natural Gas Production Industry*, p. 3-3.

4. *NO_x Emissions from Petroleum Industry Operations*, API Publication 4311, American Petroleum Institute, Washington, D.C., 1979, p. 13.

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6. *Introduction to Oil and Gas Production*, Book 1 of the Vocational Training Series, American Petroleum Institute, Dallas, 1983, p. 51.

7. *Introduction to Oil and Gas Production*, p. 52.

8. *Industrial Process for Environmental Use*, pp. 53, 55.

9. *Industrial Process Profiles for Environmental Use*, p. 14.

10. *Evaluation of Control Technologies for Hazardous Air Pollutants*, Final Report, Radian Corp., Research Triangle Park, N.C., 1985, p. 3-9.

11. *Evaluation of Control Technologies for Hazardous Air Pollutants*, p. 3-14.

3.6.2 Tank Farm Emissions

3.6.2 Tank Farm Emissions

Source of Emissions Data

The following information was obtained from:

U.S. Environmental Protection Agency, 1985 and ff. *Compilation of Air Pollutant Emission Factors, Volume I: Stationary Point and Area Sources* (Fourth Edition). Section 12.1.

Estimating Emissions

General Description.[1,2] Storage vessels containing organic liquids can be found in many industries, including petroleum producing and refining, petrochemical and chemical manufacturing, bulk storage and transfer operations, and other industries consuming or producing organic liquids. Organic liquids in the petroleum industry, usually called petroleum liquids, generally are mixtures of hydrocarbons having dissimilar true vapor pressures (for example, gasoline and crude oil).

Three basic tank designs are used for petroleum liquid storage vessels: fixed roof (vertical and horizontal), external floating roof, and internal floating roof. A brief description of each tank is provided below.

The emission estimating equations presented in this section were developed by the American Petroleum Institute, which retains the copyright to these equations. The American Petroleum Institute has granted permission for the nonexclusive, noncommercial distribution of this material to governmental and regulatory agencies. However, the American Petroleum Institute reserves its rights regarding all commercial duplication and distribution of its material. Therefore, the material presented in this section is available for public use, but the material cannot be sold without written permission from the American Petroleum Institute and EPA.

Fixed Roof Tanks. A typical vertical fixed roof tank is shown in Figure 3.6.2-1. This type of tank consists of a cylindrical steel shell with a permanently affixed roof, which may vary in design from cone- or dome-shaped to flat.

Fixed roof tanks are either freely vented or equipped with a pressure/vacuum vent. The latter allows them to operate at a slight internal pressure or vacuum to prevent the release of vapors during very small changes in temperature, pressure, or liquid level. Of current tank designs, the fixed roof tank is the least expensive to construct and is generally considered the minimum acceptable equipment for storing organic liquids.

External Floating Roof Tanks. A typical external floating roof tank consists of an open-topped cylindrical steel shell equipped with a roof that floats on the surface of the stored liquid. Floating roof tanks that are currently in use are constructed of welded steel plate and are of two general types: pontoon or double-deck. Pontoon-type and double-deck-type external floating roofs are shown in Figures 3.6.2-2 and 3.6.2-3, respectively. With all types

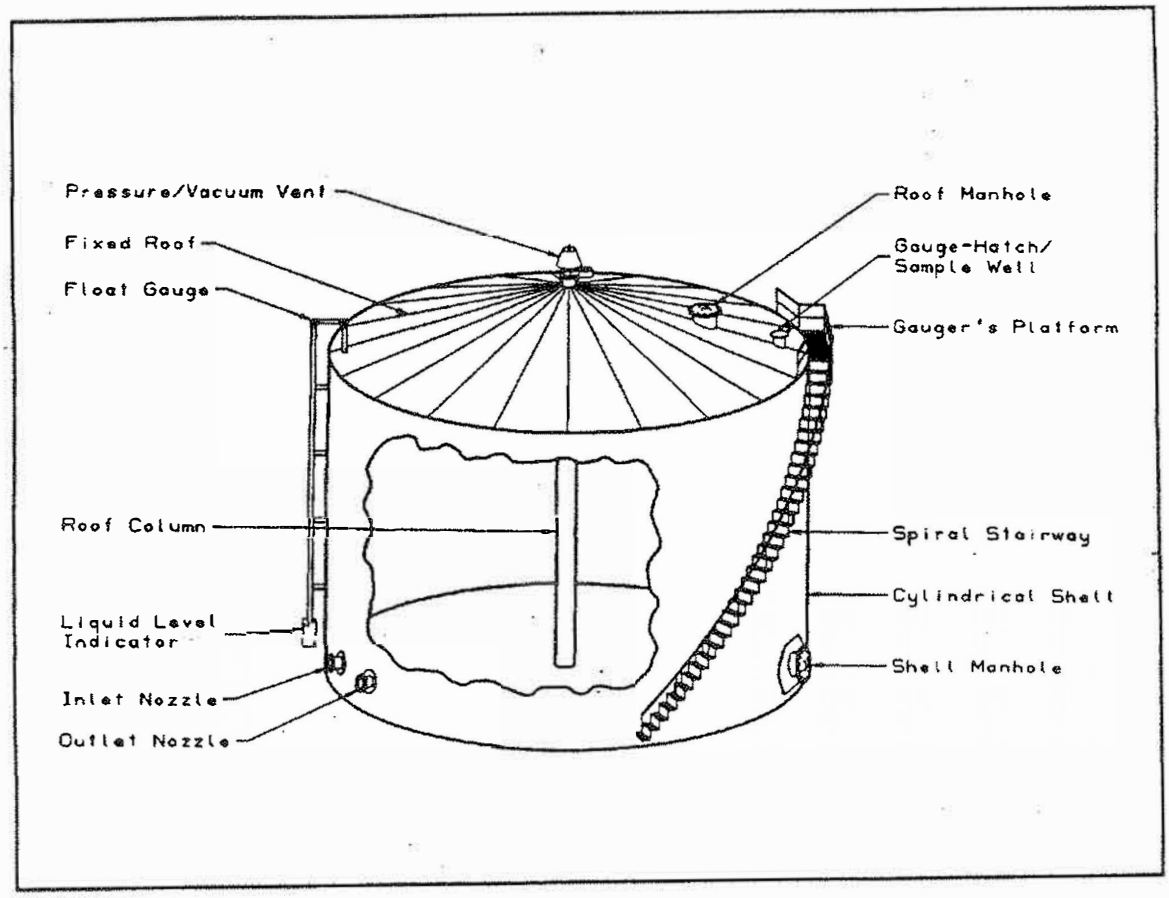


FIGURE 3.6.2-1

Typical Fixed-Roof Tank

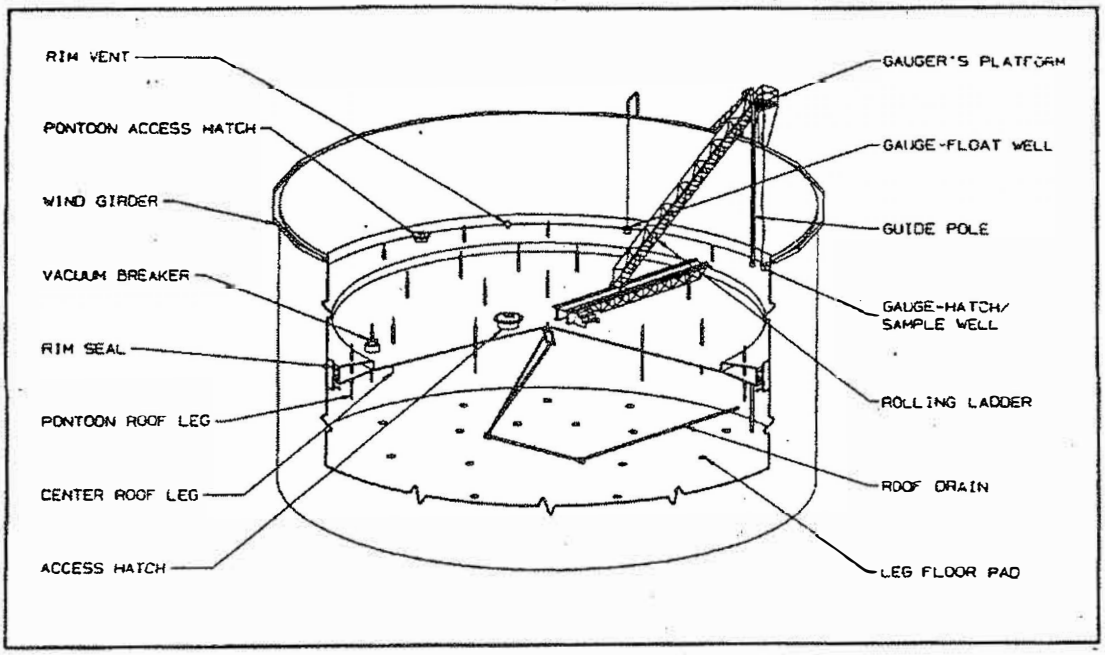


FIGURE 3.6.2-2 External Floating Tank (pontoon type)

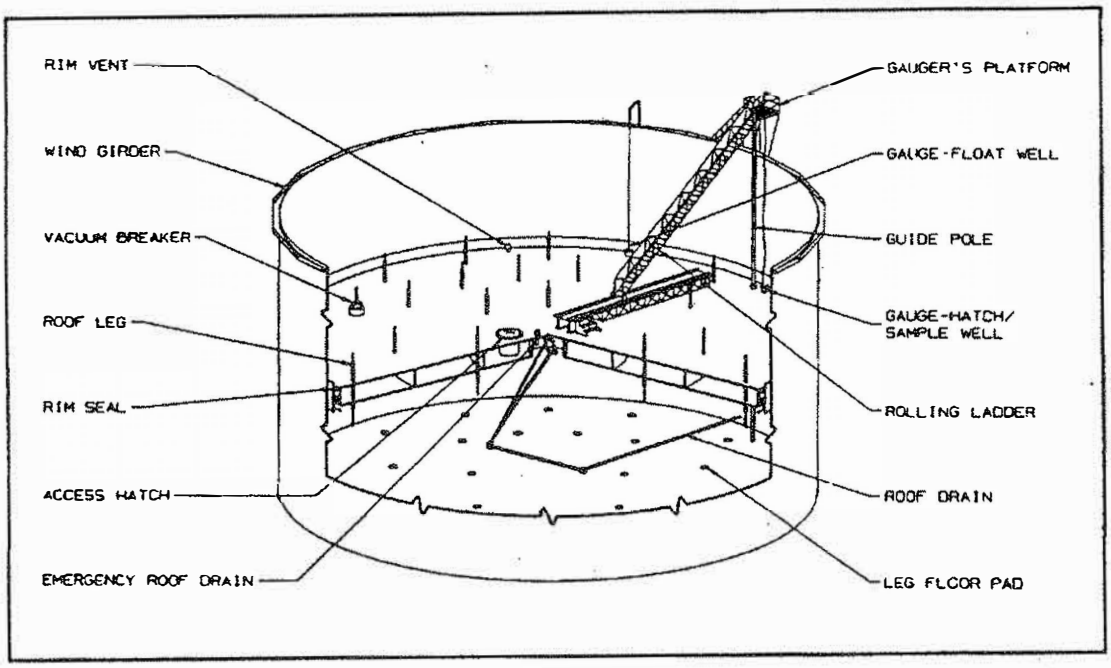


FIGURE 3.6.2-3 External Floating Tank (double-deck type)

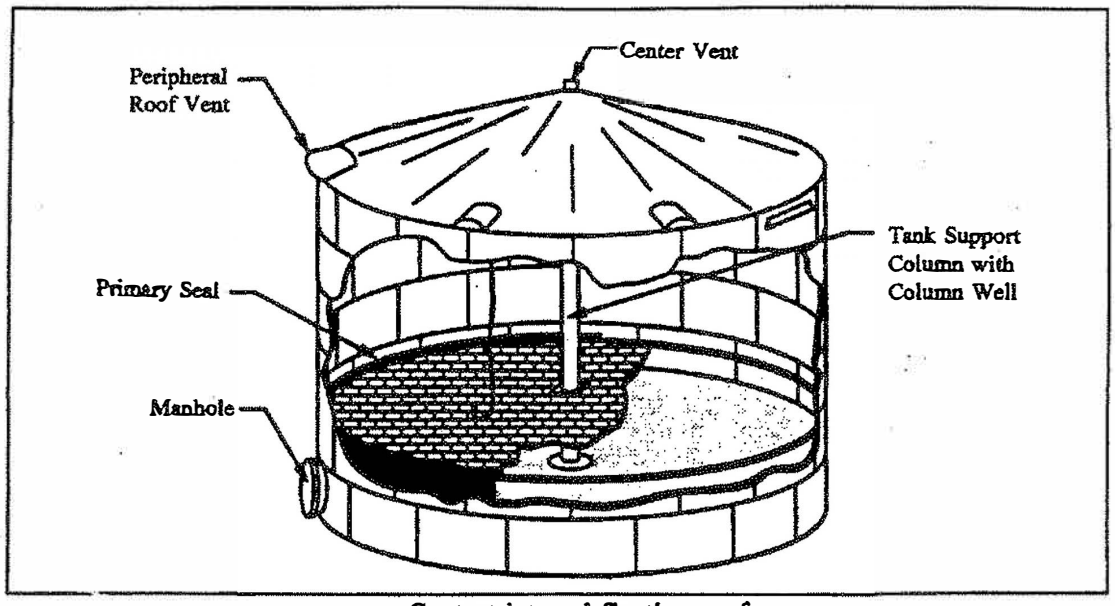
of external floating roof tanks, the roof rises and falls with the liquid level in the tank. External floating roof tanks are equipped with a seal system, which is attached to the roof perimeter and contacts the tank wall. The purpose of the floating roof and seal system is to reduce evaporative loss of the stored liquid. Some annular space remains between the seal system and the tank wall. The seal system slides against the tank wall as the roof is raised and lowered. The floating roof is also equipped with roof fittings that penetrate the floating roof and serve operational functions. The external floating roof design is such that evaporative losses from the stored liquid are limited to losses from the seal system and roof fittings (standing storage loss) and any exposed liquid on the tank walls (withdrawal loss).

Internal Floating Roof Tanks. An internal floating roof tank has both a permanent fixed roof and a floating deck inside. The terms "deck" and "floating roof" can be used interchangeably in reference to the structure floating on the liquid inside the tank. There are two basic types of internal floating roof tanks: tanks in which the fixed roof is supported by vertical columns within the tank, and tanks with a self-supporting fixed roof and no internal support columns. Fixed roof tanks that have been retrofitted to use a floating deck are typically of the first type. External floating roof tanks that have been converted to internal floating roof tanks typically have a self-supporting roof. Newly constructed internal floating roof tanks may be of either type. The deck in internal floating roof tanks rises and falls with the liquid level and either floats directly on the liquid surface (contact deck) or rests on pontoons several inches above the liquid surface (noncontact deck). The majority of aluminum internal floating roofs currently in service are noncontact decks. Typical contact deck and noncontact deck internal floating roof tanks are shown in Figure 3.6.2-4.

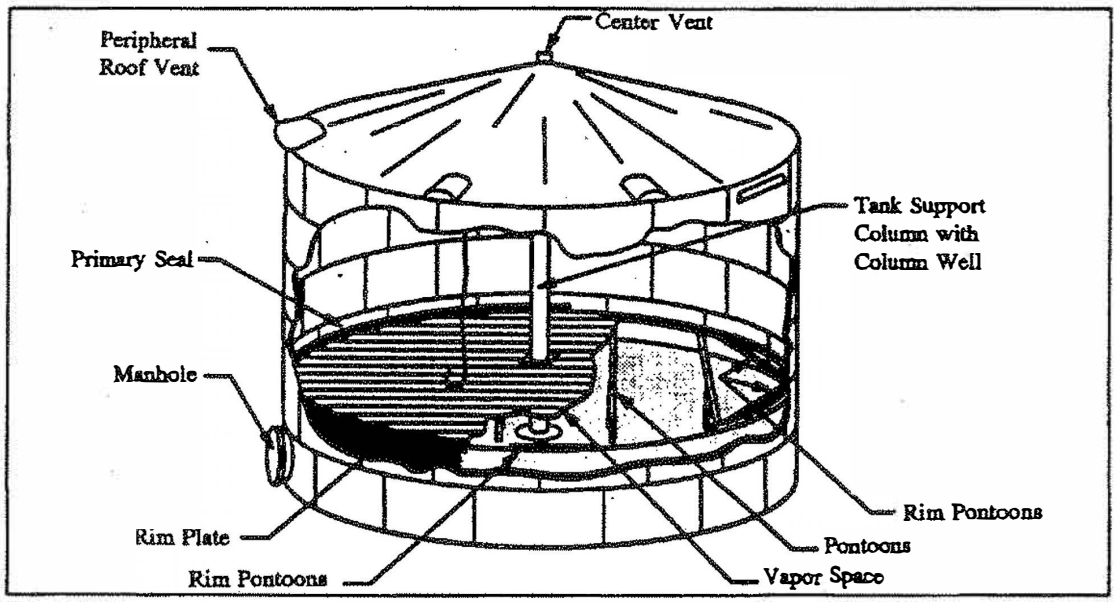
Evaporation losses from decks may come from deck fittings, nonwelded deck seams, and the annular space between the deck and tank wall. In addition, these tanks are freely vented by circulation vents at the top of the fixed roof. The vents minimize the possibility of organic vapor accumulation in concentrations approaching the flammable range. An internal floating roof tank not freely vented is considered a pressure tank. Emission estimation methods for such tanks are not provided in *AP-42*.

Emission Factor Data. The factors presented in *AP-42,* Section 12.1, are those that are currently available and have been reviewed and approved by EPA. As storage tank equipment vendors design new floating decks and equipment, new emission factors may be developed based on that equipment. If the new emission factors are reviewed and approved, the emission factors will be added to *AP-42* during the next update.

The emission estimation procedures outlined in *AP-42*, Section 12.1, have been used as the basis for the development of a software program to estimate emissions from storage tanks. The emission factor estimation procedures are not reproduced in this desk reference because they are very detailed. It is recommended that the user of this guide use the TANKS software program to estimate pollutant emissions. The TANKS program described below is available through the Technology Transfer Network BBS and has been provided on disk in Appendix D.



a. Contact internal floating roof



b. Noncontact internal floating roof.

PDX15CA0.WP5

FIGURE 3.6.2-4 Internal Floating Roof Tanks

Emissions Model. The TANKS program is designed to estimate emissions of organic chemicals from storage tanks. After the user provides specific information concerning a storage tank and its liquid contents, the system produces a report that estimates the chemical emissions for the tank on an annual or partial-year basis. If the user identifies each chemical component in a stored mixture, the system will use a HAP-speciation methodology to provide a breakdown of the storage tank emissions by chemical component.

The TANKS program relies on a chemical database of more than 100 organic liquids and a meteorological database that includes more than 175 cities in the United States; users may add new chemicals and cities to these databases by providing specific information through system utilities. An online help system provides documentation and user assistance for each screen of the program.

The program was written in FoxPro 2.5, a dBase-compatible language, and was intended for distribution by EPA through the CHIEF electronic bulletin board or through the mail on diskette. It was developed for use on IBM AT class computers with 640 KB of RAM and at least 2.5 MB of hard disk space. The program will perform faster on a 386 PC with additional RAM.

Emission Calculations. This section does not demonstrate the estimation of pollutant emissions using the equations in *AP-42*, Section 12.1. If specific details on the emission factor estimation procedures is desired, *AP-42* is available from EPA's bulletin board system or the NTIS.

Hazardous Air Pollutants. The TANKS program can automatically calculate annual or monthly HAP emissions from storage tanks. The program contains files summarizing generic information for four tank types: vertical fixed roof, horizontal fixed roof, external floating roof, and internal floating roof. Once the tank type is selected, the files can easily be modified using specific tank, site, and chemical information for the tank to be evaluated. Please refer to the user's manual (provided on disk with the TANKS program in Appendix D) for detailed instructions on how to use this program.

Mitigation Techniques

Emissions from organic liquids in storage occur because of evaporative loss of the liquid during its storage and as a result of changes in the liquid level. The emission sources vary with tank design, as does the relative contribution of each type of emission source. Emissions from fixed roof tanks are a result of evaporative losses during storage and are known as breathing losses (or standing storage losses), and evaporative losses during filling and emptying operations are known as working losses. External and internal floating roof tanks are emission sources because of evaporative losses that occur during standing storage and withdrawal of liquid from the tank. Standing storage losses are a result of evaporative losses through rim seals, deck fittings, and/or deck seams. The loss mechanisms for fixed roof and external and internal floating roof tanks are described in more detail in the following sections.

Fixed Roof Tanks. The two significant types of emissions from fixed roof tanks are storage and working losses. Storage loss is the expulsion of vapor from a tank through vapor expansion and contraction, which are the results of changes in temperature and barometric pressure. This loss occurs without any liquid level change in the tank.

The combined loss from filling and emptying is called working loss. Evaporation during filling operations is a result of an increase in the liquid level in the tank. As the liquid level increases, the pressure inside the tank exceeds the relief pressure and vapors are expelled from the tank. Evaporative loss during emptying occurs when air drawn into the tank during liquid removal becomes saturated with organic vapor and expands, thus exceeding the capacity of the vapor space.

Fixed roof tank emissions vary as a function of vessel capacity, vapor pressure of the stored liquid, utilization rate of the tank, and atmospheric conditions at the tank location.

Several methods are used to control emissions from fixed roof tanks. Emissions from fixed roof tanks can be controlled by installing an internal floating roof and seals to minimize evaporation of the product being stored. The control efficiency of this method ranges from 60 to 99 percent, depending on the type of roof and seals installed and on the type of organic liquid stored.

Vapor balancing is another means of emission control. Vapor balancing is probably most common in the filling of tanks at gasoline stations. As the storage tank is filled, the vapors expelled from the storage tank are directed to the emptying gasoline tanker truck. The truck then transports the vapors to a centralized station where a vapor recovery or control system is used to control emissions. Vapor balancing can have control efficiencies as high as 90 to 98 percent if the vapors are subjected to vapor recovery or control. If the truck vents the vapor to the atmosphere instead of to a recovery or control system, no control is achieved.

Vapor recovery systems collect emissions from storage vessels and convert them to liquid product. Several vapor recovery procedures may be used, including vapor/liquid absorption, vapor compression, vapor cooling, vapor/solid adsorption, or a combination of these. The overall control efficiencies of vapor recovery systems are as high as 90 to 98 percent, depending on the methods used, the design of the unit, the composition of vapors recovered, and the mechanical condition of the system.

In a typical thermal oxidation system, the air/vapor mixture is injected through a burner manifold into the combustion area of an incinerator. Control efficiencies for this system can range from 96 to 99 percent.

External Floating Roof Tanks[2,3,5]. Total emissions from external floating roof tanks are the sum of withdrawal losses and standing storage losses. Withdrawal losses occur as the liquid level, and thus the floating roof, is lowered. Some liquid remains attached to the tank surface and is exposed to the atmosphere. Evaporative losses will occur until the tank is filled and the exposed surface (with the liquid) is again covered. Standing storage losses from external floating roof tanks include rim seal and roof fitting losses. Rim seal losses can occur

through many complex mechanisms, but the majority of rim seal vapor losses have been found to be wind-induced. Other potential standing storage loss mechanisms include breathing losses as a result of temperature and pressure changes. Also, standing storage losses can occur through permeation of the seal material with vapor or via a wicking effect of the liquid. Testing has indicated that breathing, solubility, and wicking loss mechanisms are small in comparison to the wind-induced loss. Also, permeation of the seal material generally does not occur if the correct seal fabric is used. The rim seal loss factors incorporate all types of losses.

The roof fitting losses can be explained by the same mechanisms as the rim seal loss mechanisms. However, the relative contribution of each is not known. The roof fitting losses identified in this section account for the combined effect of all of the mechanisms.

A rim seal system is used to allow the floating roof to travel within the tank as the liquid level changes. The seal system also helps to fill the annular space between the rim and the tank shell and therefore minimize evaporative losses from this area. A rim seal system may consist of just a primary seal or a primary seal and a secondary seal, which is mounted above the primary seal. Examples of primary and secondary seal configurations are shown in Figures 3.6.2-1 through 3.6.2-3. Three basic types of primary seals are used on external floating roofs: mechanical (metallic) shoe, resilient filled (nonmetallic), and flexible wiper. The resilient seal can be mounted to eliminate the vapor space between the seal and liquid surface (liquid mounted) or to allow a vapor space between the seal and liquid surface (vapor mounted). A primary seal serves as a vapor conservation device by closing the annular space between the edge of the floating roof and the tank wall. Some primary seals are protected by a metallic weather shield. Additional evaporative loss may be controlled by a secondary seal. Secondary seals can be either flexible wiper seals or resilient filled seals. Two configurations of secondary seals are currently available: shoe mounted and rim mounted. Although there are other seal systems, the systems described here include the majority in use today.

Internal Floating Roof Tanks[4,5] . Total emissions from internal floating roof tanks are the sum of withdrawal losses and standing storage losses. Withdrawal losses occur in the same manner as in external floating roof tanks: as the floating roof lowers, some liquid remains attached to the tank surface and evaporates. Also, in internal floating roof tanks that have a column-supported fixed roof, some liquid clings to the columns. Standing storage losses from internal floating roof tanks include rim seal, deck fitting, and deck seam losses. However, unlike external floating roof tanks in which wind is the predominant factor affecting rim seal loss, no dominant wind loss mechanism has been identified for internal floating roof tank rim seal losses. Deck seams in internal floating roof tanks are a source of emissions to the extent that these seams may not be completely vapor tight.

Internal floating roofs typically incorporate one of two types of flexible, product-resistant seals: resilient foam-filled seals or wiper seals. Similar to those used on external floating roofs, each of these seals closes the annular vapor space between the edge of the floating roof and the tank shell to reduce evaporative losses. They are designed to compensate for small

irregularities in the tank shell and allow the roof to move freely up and down in the tank without binding.

Numerous deck fittings penetrate or are attached to an internal floating roof. These fittings accommodate structural support members or allow for operational functions. The fittings can be a source of evaporative loss in that they require penetrations in the deck. Other accessories are used that do not penetrate the deck and are not, therefore, sources of evaporative loss.

References

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3.7.1 Wind Erosion of Bare or Vegetated Soil

3.7 Miscellaneous

3.7.1 Wind Erosion on Bare or Vegetated Soil

Source of Emissions Data

Information for this section was adapted from Troeh et al. (1991).[1]

Estimating Emissions

A simple yet effective means of predicting soil loss that is a result of the mechanical action of wind on bare or vegetated soil areas is the wind-erosion prediction equation (WEQ)[1]. The primary uses for the WEQ are: (1) assessment of the existing wind erosion hazard for a particular site (measured in terms of soil loss), and (2) evaluation of the future effects of various management alternatives (e.g., grazing, afforestation, reforestation, grass seeding).

Wind-Erosion Prediction Equation. The wind-erosion prediction equation is:

$$E = f\,(E_3,\ V)$$

where

$$E_1 = I' \cdot K'$$

$$E_2 = I' \cdot K' \cdot C'$$

$$E_3 = g\,(E_1,\ E_2,\ L')$$

and where	E	=	predicted soil loss, tons/acre/year
	I'	=	soil-erodibility factor, tons/acre/year
	K'	=	soil ridge roughness factor, dimensionless
	C'	=	climatic factor, dimensionless
	L'	=	width-of-field factor, dimensionless
	V	=	vegetative-cover factor, dimensionless

The WEQ includes the major factors that influence the severity of wind erosion: soil erodibility, soil roughness, climate, orientation of the field to the predominant winds (width-of-field factor), and vegetative cover. Each of these factors is described below.

Soil-Erodibility Factor (I'). Soil erodibility is the "*potential annual soil loss from a wide, unsheltered, isolated field with a bare, smooth, noncrusted surface.*"[1] In practice, the soil-erodibility factor (I') is the product of a soil "cloddiness" factor (I) and a "knoll-steepness" factor (I_s):

$$I' = I \cdot I_s$$

Soil "cloddiness" refers to the percentage of the soil surface occupied by nonerodible "clods" greater than 0.84 mm in diameter. The greater the percentage of nonerodible clods, the greater the sheltering of individual soil grains against the wind and the lower the resultant soil loss. Soil erodibility is also a function of "knoll-steepness"; that is, the slope angle and the soil's position on the slope. The greater the slope angle, the greater the probability that the mechanical action of the wind will result in soil movement (erosion); also, soil on the tops of knolls has a higher rate of soil loss than soil on the sides because of exposure to the wind.

Table 3.7.1-1 and Figure 3.7.1-1 contain soil "cloddiness" and "knoll-steepness" values, respectively. The values in Table 3.7.1-1 are predicted soil losses (in tons/acre/year) for different degrees of soil cloddiness. For example, a soil on level land with 25 percent cloddiness would have a predicted loss of 86 tons/acre/year.

Percentages (tens)	Percentages (units)									
	0	1	2	3	4	5	6	7	8	9
	tons/ac-yr									
0		310	250	220	195	180	170	160	150	140
10	134	131	128	125	121	117	113	109	106	102
20	98	95	92	90	88	86	83	81	79	76
30	74	72	71	69	67	65	63	62	60	58
40	56	54	52	51	50	48	47	45	43	41
50	38	36	33	31	29	27	26	24	23	22
60	21	20	19	18	17	16	16	15	14	13
70	12	11	10	8	7	6	4	3	3	2
80	2	—	—	—	—	—	—	—	—	—

Table 3.7.1-1 Soil Erodibility (*I*) Values in Tons/AC-YR[a] for Soils with Various Percentages of Nonerodible Clods (> 0.84 mm diameter) as Determined by Standard Dry Sieving

[a]To convert tons/ac-yr to mt/ha-yr, multiply each value by 2.24.

Source: Reproduced from *Soil Science Society of America Proceedings*, Volume 29, p 602–608, 1965 (Woodruff and Siddoway), by permission of the Soil Science Society of America.

A soil scientist should be consulted to determine the percent of nonerodible clods in a particular soil.

The values in Figure 3.7.1-1 are the relationships, in percent, of soils on different slopes to their erodibilities on level land. For example, the soil loss for a short 4% slope is approximately 195% greater on the crests of knolls (line (a) in the figure), and 160% greater on the upper windward slopes (line (b) in the figure), than the soil loss on level ground. Note that these values are applied as percentage adjustments to the soil losses shown in Table 3.7.1-1.

These values are based on wind-tunnel relative erodibilities, coupled with soil losses measured in the vicinity of Garden City, Kansas, during 1954-1956, an excessively dry and windy period[2]. Conversion of the relative erodibility to field loss must be considered an approximation at present because of difficulty in measuring soil losses[3].

The literature suggests that surface crusts reduce soil erosion and should be considered in estimating potential erosion. In practice, however, soil crusts are seldom accounted for in the estimation of soil loss because of the transitory nature of the crusts[1].

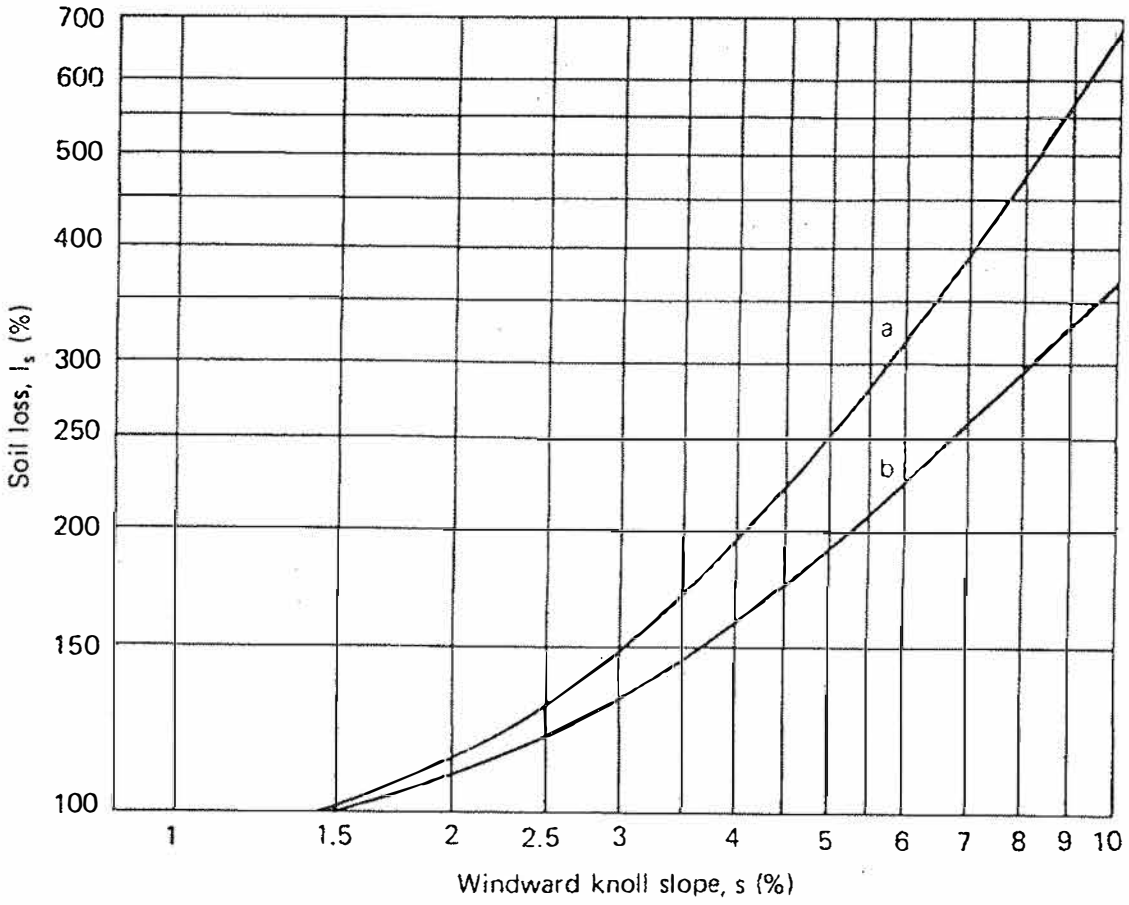

Figure 3.7.1-1 Potential soil loss, I_s, from (a) the crest of knolls and from (b) the upper third of the windward side of slopes < 500 ft. (150 m) long as percentages of I_s on level land. (Reproduced from *Soil Science Society of America Proceedings*, Volume 29, p. 602–608, 1965 [Woodruff and Siddoway], by permission of the Soil Science Society of America.)

Soil-Ridge-Roughness Factor (K'). Soil-ridge roughness is the second of three factors that affect the overall surface roughness. The others include soil "cloddiness" (I; discussed previously), and vegetative cover (V; discussed later). Soil-ridge roughness is a measure of the roughness of the soil surface. It also determines the "sheltering" (shadowing) effect of ridges on the displacement of individual soil particles. The rougher (i.e., more sheltered) the soil surface, the lower the opportunity for the wind to displace soil particles.

Table 3.7.1-2 shows the relative erodibility of soils with different ridge heights and spacings, following the work of Skidmore (1983)[4].

If the heights and spacings of soil ridges are not known, then a K' value of 1.00 should be used in the WEQ (conservative).

Ridge spacing (in.)	Ridge height (in.)											
	1	2	3	4	5	6	7	8	9	10	11	12
1	0.5	0.8										
2	0.5	0.6	0.8									
4	0.6	0.5	0.7	0.8								
6	0.7	0.5	0.6	0.8								
8	0.8	0.5	0.5	0.6	0.8							
10	0.8	0.6	0.5	0.6	0.8							
12	0.9	0.6	0.5	0.5	0.7	0.8						
14	0.9	0.6	0.5	0.5	0.6	0.8						
16	0.9	0.6	0.5	0.5	0.6	0.7	0.8					
18	0.9	0.7	0.5	0.5	0.5	0.6	0.8					
20	0.9	0.7	0.5	0.5	0.5	0.6	0.8					
22	0.9	0.7	0.6	0.5	0.5	0.6	0.7	0.8				
24	0.9	0.7	0.6	0.5	0.5	0.6	0.7	0.8				
26	0.9	0.8	0.6	0.5	0.5	0.5	0.6	0.8				
28	0.9	0.8	0.6	0.5	0.5	0.5	0.6	0.7	0.8			
30	0.9	0.8	0.6	0.5	0.5	0.5	0.6	0.7	0.8			
32	1.0	0.8	0.6	0.5	0.5	0.5	0.6	0.6	0.8			
34	1.0	0.8	0.6	0.5	0.5	0.5	0.5	0.6	0.7	0.8		
36	1.0	0.8	0.6	0.5	0.5	0.5	0.5	0.6	0.7	0.8		
38	1.0	0.8	0.6	0.6	0.5	0.5	0.5	0.6	0.7	0.8		
40	1.0	0.8	0.7	0.6	0.5	0.5	0.5	0.6	0.7	0.8		
42	1.0	0.9	0.7	0.6	0.5	0.5	0.5	0.6	0.6	0.7	0.8	
44	1.0	0.9	0.7	0.6	0.5	0.5	0.5	0.5	0.6	0.7	0.8	
46	1.0	0.9	0.7	0.6	0.5	0.5	0.5	0.5	0.6	0.7	0.8	
48	1.0	0.9	0.7	0.6	0.5	0.5	0.5	0.5	0.6	0.7	0.8	

Table 3.7.1-2 Soil Ridge-Roughness Factor (*K'*) Values

Source: From the *Journal of Soil and Water Conservation*, Volume 38, p. 110–112, 1983 (Skidmore).

Climatic Factor (C'). The climatic factor (C') used in the WEQ is the climate factor (C) for the subject site expressed as a percentage of the C value at Garden City, Kansas (where soil erodibility data used to define I' were obtained). That is:

$$C' = \left(\frac{C_{site}}{C_{Garden\,City,\,Kansas}}\right) \cdot 100 = \left(\frac{C_{site}}{2.9}\right) \cdot 100 = 34.8 \cdot C_{site}$$

The climate factor for a specific site (C_{site}) is:

$$C_{site} = \frac{c_1 \cdot u^3}{(PE)^2}$$

where u = annual-average windspeed (mph)
PE = Thornthwaite's Precipitation-Evaporation Index (dimensionless)
c_1 = constant to correct units (1 mph^{-3})

Thornthwaite's (1931)[5] Precipitation-Evaporation Index (PE) is a measure of the atmospheric humidity, and accounts for the direct effects of humidity and soil moisture on soil cohesiveness and resistance to erosion. The more frequently soils are moistened by rains, and the longer they remain moist after each rain, the more difficult it is for the wind to dislodge the soil particles.

The PE Index[1] is computed as follows:

$$PE = c_2 \cdot 115 \cdot \sum_{i=1}^{12} \left(\frac{P}{T - 10°F}\right)_i^{10/9}$$

where P = monthly precipitation (inches)
T = monthly mean temperature (°F)
c_2 = constant to correct units [1 $inches^{(10/9)} °F^{-(10/9)}$]
i = index for month of year (i=1,2,...,12)

Thornthwaite (1931) used 28.4°F as the minimum mean monthly temperature--even at higher latitudes where mean temperatures are below freezing for several months of the year--with consequent reductions in evaporation and with precipitation that falls nonerosively as snow.

To reduce the opportunity for erroneously high C_{site} values in the drier regions of the U.S., Chepil (1960) suggests a minimum monthly precipitation value of 0.5 inch.

Chepil et al. (1962)[6] developed a generalized climatic erosiveness map for the western half of the United States (Figure 3.7.1-2). This map may be used to approximate the C' values for different geographic regions. The Soil Conservation Service may have prepared more detailed C' value data for these states[1].

Width-of-Field Factor (L'). The width-of-field factor (L') is the difference between the median *unsheltered* (i.e., open, unprotected) travel distance across a field (called the median travel distance, or MTD) and the median *sheltered* distance across the field (i.e., the wind-protected distance across a field). For simplicity, the latter is assumed to be roughly 10 times the height of adjacent barriers (B) such as hedgerows and shelterbelts. The equation is:

$$L' = MTD - 10 \cdot B$$

Calculation of the MTD involves: (1) the physical dimensions of the field, and (2) the orientation of the predominant winds along the major and minor axes of a field, which is assumed to be elliptical in form. The orientation of the winds is measured by the *wind-direction factor* (D_f). Tables 3.7.1-3, 3.7.1-4, and 3.7.1-5 show the wind-direction factors for three field configurations (length-to-width ratios): 2, 4, and 10. These direction factors are used to scale the actual field lengths to give the MTD across the field.

$$MTD = \text{Field Length (feet)} \cdot D_f$$

Use of the wind-direction factor tables requires knowledge of the deviation of the prevailing wind direction from the major axis of the field and the wind *preponderance factor*. The wind preponderance factor indicates the proportion of wind-erosion forces oriented parallel to, as opposed to perpendicular to, the prevailing wind direction. A preponderance of 1.0 means that there is no prevailing wind direction. A preponderance of 4.0 mean that there is a prevailing wind direction, and that four times as much erosive force is oriented parallel to the prevailing wind direction as perpendicular to it.

Preponderance values and directions of prevailing winds may be obtained from Skidmore (1987)[7] or from individual Soil Conservation Service offices.

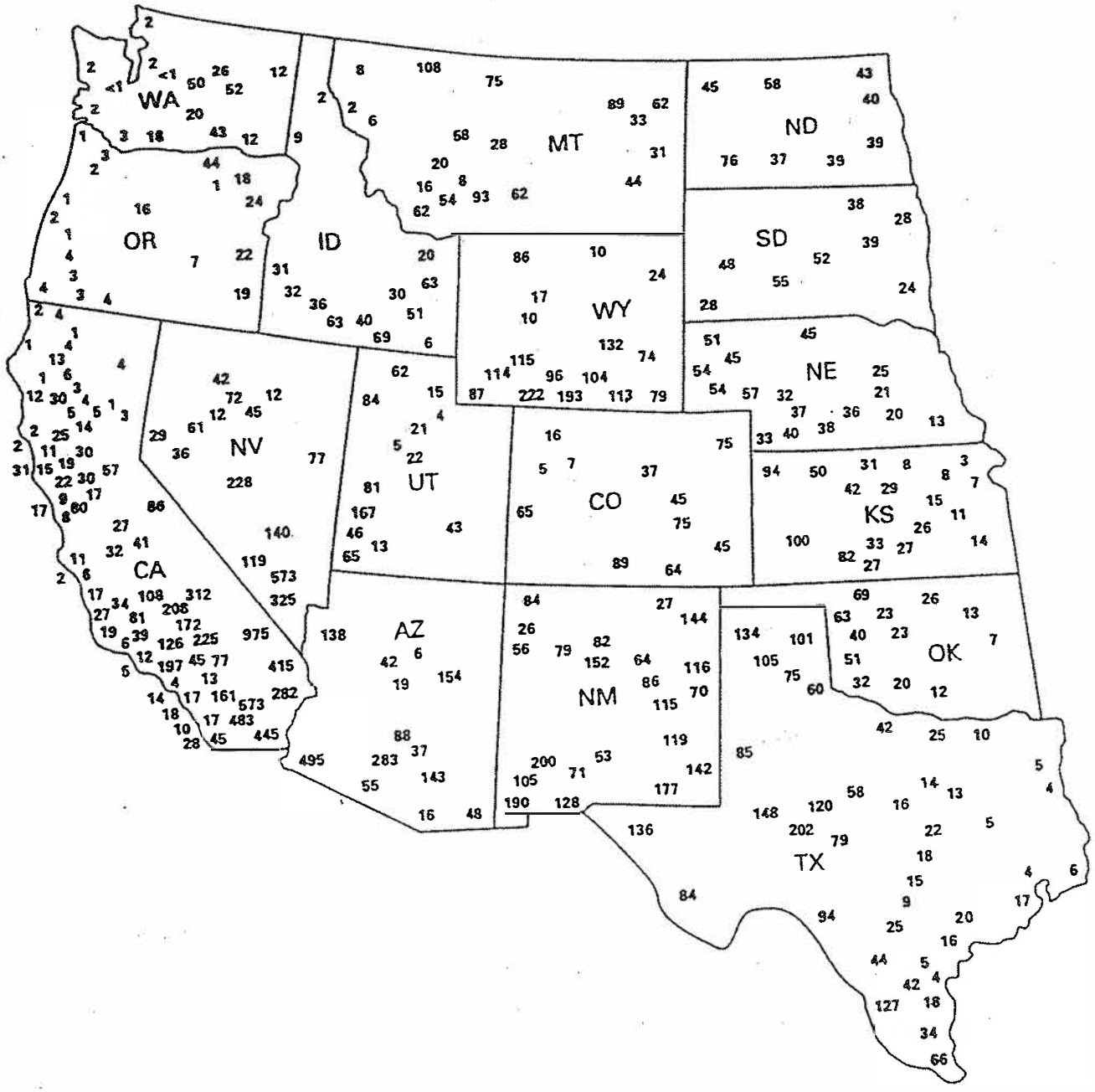

Figure 3.7.1-2 Wind-erosion climatic factor C' in percent of the value at Garden City, Kansas. [From the *Journal of Soil and Water Conservation*, Volume 38, p. 106--109, 1983 (Lyles).]

Pre-ponderance	Angle of deviation (degrees)								
	0.00	11.25	22.50	33.75	45.00	56.25	67.50	78.75	90.00
1.0	1.42	1.42	1.42	1.42	1.42	1.42	1.42	1.42	1.42
1.2	1.30	1.31	1.35	1.40	1.42	1.43	1.44	1.46	1.46
1.4	1.20	1.21	1.27	1.36	1.42	1.44	1.48	1.52	1.55
1.6	1.14	1.15	1.22	1.32	1.42	1.46	1.53	1.62	1.66
1.8	1.10	1.11	1.18	1.29	1.42	1.47	1.58	1.72	1.80
2.0	1.07	1.09	1.16	1.28	1.42	1.47	1.62	1.82	1.96
2.2	1.05	1.07	1.14	1.27	1.42	1.48	1.65	1.94	2.00
2.4	1.04	1.06	1.13	1.26	1.42	1.49	1.68	1.97	2.00
2.6	1.03	1.05	1.12	1.26	1.42	1.49	1.70	1.99	2.00
2.8	1.02	1.04	1.12	1.25	1.42	1.50	1.72	2.00	2.00
3.0	1.02	1.04	1.12	1.25	1.42	1.50	1.73	2.00	2.00
3.2	1.01	1.04	1.12	1.25	1.42	1.50	1.74	2.00	2.00
3.4	1.01	1.04	1.12	1.25	1.42	1.50	1.74	2.01	2.00
3.6	1.01	1.04	1.12	1.25	1.42	1.50	1.75	2.01	2.00
3.8	1.01	1.04	1.11	1.25	1.42	1.50	1.76	2.02	2.00
4.0	1.01	1.04	1.11	1.25	1.42	1.51	1.76	2.02	2.00

Table 3.7.1-3 Wind-Erosion Direction Factor (Df) for Rectangular Fields with Length/Width Ratio of 2

Source: Modified from *Soil Science Society of America Journal*, Volume 51, p. 198–202, 1987 (Skidmore) by permission of the Soil Science Society of America.

Pre-ponderance	Angle of deviation (degrees)								
	0.00	11.25	22.50	33.75	45.00	56.25	67.50	78.75	90.00
1.0	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48
1.2	1.30	1.31	1.35	1.40	1.48	1.57	1.66	1.72	1.76
1.4	1.20	1.21	1.27	1.36	1.48	1.65	1.86	2.00	2.00
1.6	1.14	1.15	1.22	1.32	1.48	1.72	1.98	2.24	2.35
1.8	1.10	1.11	1.18	1.29	1.48	1.77	2.08	2.43	2.55
2.0	1.07	1.09	1.16	1.28	1.48	1.82	2.17	2.58	2.78
2.2	1.05	1.07	1.14	1.27	1.48	1.85	2.20	2.74	3.06
2.4	1.04	1.06	1.13	1.26	1.48	1.86	2.38	2.89	3.35
2.6	1.03	1.05	1.12	1.26	1.48	1.87	2.42	3.02	3.58
2.8	1.02	1.04	1.12	1.25	1.48	1.88	2.44	3.15	3.74
3.0	1.02	1.04	1.12	1.25	1.48	1.88	2.45	3.28	3.92
3.2	1.01	1.04	1.12	1.25	1.48	1.89	2.46	3.33	4.00
3.4	1.01	1.04	1.12	1.25	1.48	1.89	2.47	3.35	4.00
3.6	1.01	1.04	1.12	1.25	1.48	1.89	2.48	3.38	4.00
3.8	1.01	1.04	1.12	1.25	1.48	1.89	2.48	3.39	4.00
4.0	1.01	1.04	1.11	1.25	1.48	1.90	2.48	3.41	4.00

Table 3.7.1-4 Wind-Erosion Direction Factor (Df) for Rectangular Fields with Length/Width Ratio of 4

Source: Modified from *Soil Science Society of America Journal*, Volume 51, p. 198–202, 1987 (Skidmore) by permission of the Soil Science Society of America.

Pre-ponderance	Angle of deviation (degrees)								
	0.00	11.25	22.50	33.75	45.00	56.25	67.50	78.75	90.00
1.0	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48
1.2	1.30	1.31	1.35	1.40	1.48	1.57	1.66	1.72	1.76
1.4	1.20	1.21	1.27	1.36	1.48	1.65	1.86	1.99	2.00
1.6	1.14	1.15	1.22	1.32	1.48	1.72	1.98	2.33	2.55
1.8	1.10	1.11	1.18	1.30	1.48	1.77	2.10	2.76	3.08
2.0	1.07	1.09	1.16	1.28	1.48	1.82	2.26	3.18	3.73
2.2	1.05	1.07	1.14	1.27	1.48	1.85	2.34	3.61	4.47
2.4	1.04	1.06	1.13	1.26	1.48	1.86	2.61	4.01	5.22
2.6	1.03	1.05	1.12	1.26	1.48	1.87	2.70	4.38	5.93
2.8	1.02	1.04	1.12	1.25	1.48	1.88	2.77	4.73	6.61
3.0	1.02	1.04	1.12	1.25	1.48	1.88	2.82	5.03	7.28
3.2	1.01	1.04	1.12	1.25	1.48	1.89	2.74	5.20	7.79
3.4	1.01	1.04	1.12	1.25	1.48	1.89	2.86	5.31	8.17
3.6	1.01	1.04	1.12	1.25	1.48	1.89	2.88	5.39	8.54
3.8	1.01	1.04	1.12	1.25	1.48	1.89	2.90	5.46	8.91
4.0	1.01	1.04	1.11	1.25	1.48	1.90	2.91	5.51	9.27

Table 3.7.1-5 Wind-Erosion Direction Factor (Df) for Rectangular Fields with Length/Width Ratio of 10

Source: Modified from *Soil Science Society of America Journal*, Volume 51, p. 198–202, 1987 (Skidmore) by permission of the Soil Science Society of America.

Example: Calculation of Mean Travel Distance (MTD)

A field measuring 2,600 meters north-south and 1,300 meters east-west has a preponderance factor of 1.4 and a prevailing wind direction of 203°. The calculated length-to-width ratio is 2, and wind deviation is 23° (i.e., 203° -180° = 23°). Therefore, the wind-erosion direction factor is 1.27, and the MTD is 1,651 feet (1.27 x 2,600 feet = 1,651 feet).

Calculation of the effect of L' on soil loss (the variable E_3) is complex and requires the use of the nomograph in Figure 3.7.1-3. This nomograph incorporates soil-ridge-roughness, soil-erodibility, and climatic factors in the estimation of soil loss with consideration of vegetative cover. The figure requires the use of two composite variables, E_1 and E_2, defined previously as follows:

$$E_1 = I' \cdot K'$$

$$E_2 = I' \cdot K' \cdot C'$$

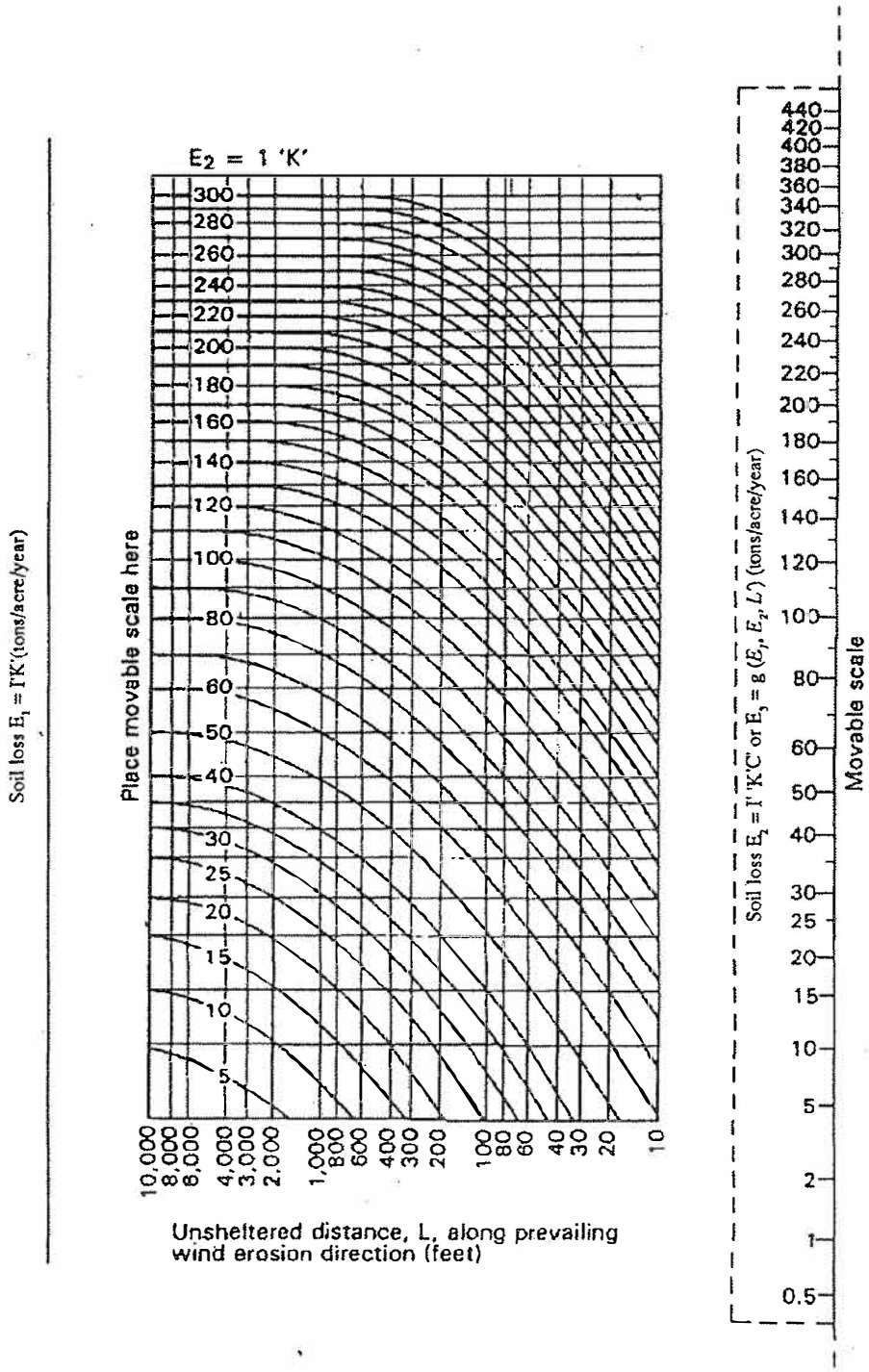

Figure 3.7.1-3 Nomogram to determine soil loss, E_3=g (E_1 ,E_2, L'), from soil loss E_1=I x K' and E_2 = I' x K' x C' and the unsheltered distance L' across the field. In use, a copy of the movable scale is placed along the left side of the graph so that E_2 on the scale is aligned with E_1 on the graph. A line parallel to the curved lines is then followed to its intersection with the unsheltered distance line. The value of E_3 is located by following a horizontal line from the intersection back to the movable scale. For example, an E_2 value of 150 and an E_1 value of 120 combined with an unsheltered distance of 600 ft give an E_3 value of 130. [From *Soil Science Society of America Proceedings*, Volume 29, p. 602-608, 1965 (Woodruff and Siddoway), by permission of the Soil Science Society of America.]

Vegetation Factor (V). The presence of a vegetation cover reduces the expected soil loss by lowering the windspeed and by sheltering the soil surface from the mechanical effects of the wind. The protection offered by vegetation depends on how much dry matter it contains, its texture, whether it is living or dead, standing or flat. Figure 3.7.1-4 may be used to assess the effectiveness of vegetation in reducing soil loss, provided the user has the necessary inputs of measured crop residues (in pounds per acre).

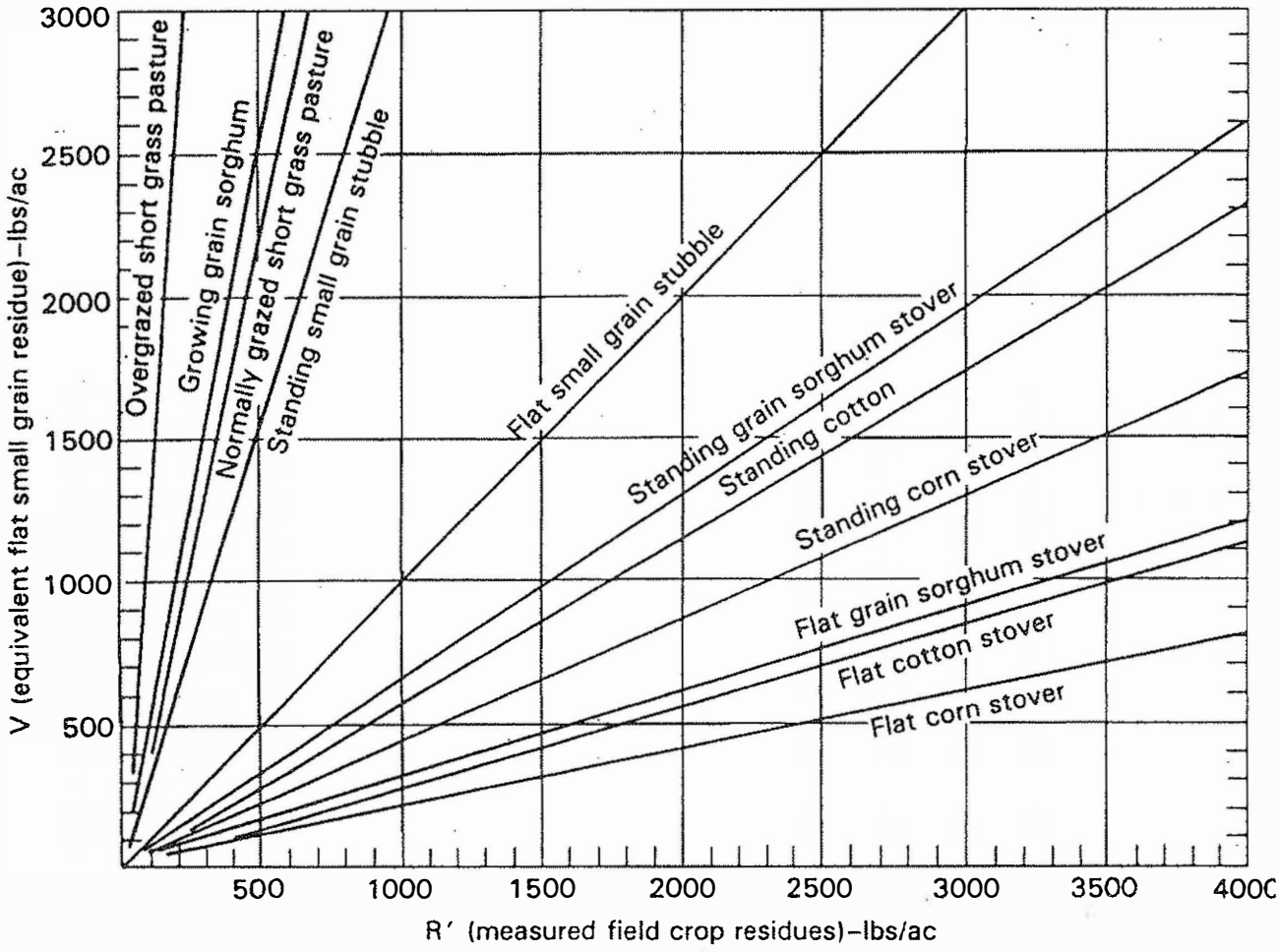

Figure 3.7.1-4 Curves to convert weights of living or dead crop material (R') into equivalent amounts of flattened wheat straw (V). [Modified from *Agronomy Journal*, Volume 77, p. 703–707, 1985 (Armbrust and Lyles) by permission of the American Society of Agronomy; *Journal of Range Management*, Volume 33, p. 143–146, 1980 (Lyles and Allison); and *Transactions of American Society of Agricultural Engineers*, Volume 24, p. 405–408, 1981 (Lyles and Allison).]

The best way to estimate the amount of surface vegetation on a particular field is to hand pick, dry, and weigh the living plants or surface residue from a fixed unit area. One square yard is sufficient for small grains; 2 square yards is necessary for row crops. At least three separate samples should be taken for a reliable estimate at each location. Soil must be removed from plants before weighing. For this, washing is much quicker than cleaning a dry sample. Results should be transferred into units of pounds per acre. For more information on vegetation sampling methods, see Troeh et al. (1990)[1].

Example–Expected Soil Losses (E) from a Field

Soil loss may be estimated using E_3 [=g(E_1, E_2, L')] and the calculated vegetation factor V (Figure 3.7.1-5).

Example

A 2,600- by 5,200-foot field with long axis east-west on Ortello fine sandy loam in Ford County, Kansas, will serve as an example. The surface soils contain 25% nonerodible clods. Several knolls with short 3% slopes are in the field. A crop of grain sorghum was produced in 30-inch rows. There is no growing crop. A total of 1,150 lbs/acre of tall standing stubble remains. The average ridge height is 6 inches. The prevailing wind direction during March is due north (deviation = 0°); the preponderance factor is 2.4.

What is the predicted soil loss from the knolls during the month of March?

Step 1: Compute E_1 = I' x K' and E_2 = I' x K' x C'

The soil erodibility factor I for 25% nonerodible clods is 86 tons/acre/year (Table 3.7.1-1).

The potential soil loss I_s from knolls of a 3% slope is 148% that of level land (Figure 3.7.1-1).

The soil erodibility factor I' is (86 tons/acre/year)(1.48) = 127 tons/acre/year.

The soil-ridge roughness factor K' for a ridge height of 6 inches and row width of 30 inches is 0.50 (Table 3.7.1-2).

The climatic factor C' for Ford County, Kansas is about 0.80 or 80% (Figure 3.7.1-2).

Therefore, the value for E_1 is (127 tons/acre/year)(0.5) = 64 tons/acre/year. The value for E_2 is (127 tons/acre/year)(0.5)(0.8) = 51 tons/acre/year.

Step 2: Compute Width-of-Field Factor, L', and E_3

The wind-erosion direction factor L' for fields with a length-to-width ratio of 2 is 1.04 (Table 3.7.1-3).

The MTD is (2,600 feet)(1.04) = 2,700 feet

Because no wind barriers were described, L' = 2,700 feet. The value of E_3 is therefore 48 tons/acre/year for E_1 = 64, E_2 = 51, and L' = 2,700 feet (Figure 3.7.1-3).

Step 3: Compute Vegetation Factor, V

The measured crop residue is 1,150 pounds per acre. Therefore, V is 750 pounds per acre (Figure 3.7.1-4; use line labeled "standing grain sorghum stover").

Step 4: Compute Soil Loss E

The value for soil loss E is 22 tons per acre given E_3 = 48 tons/acre/year and V = 750 lbs/acre (Figure 3.7.1-5).

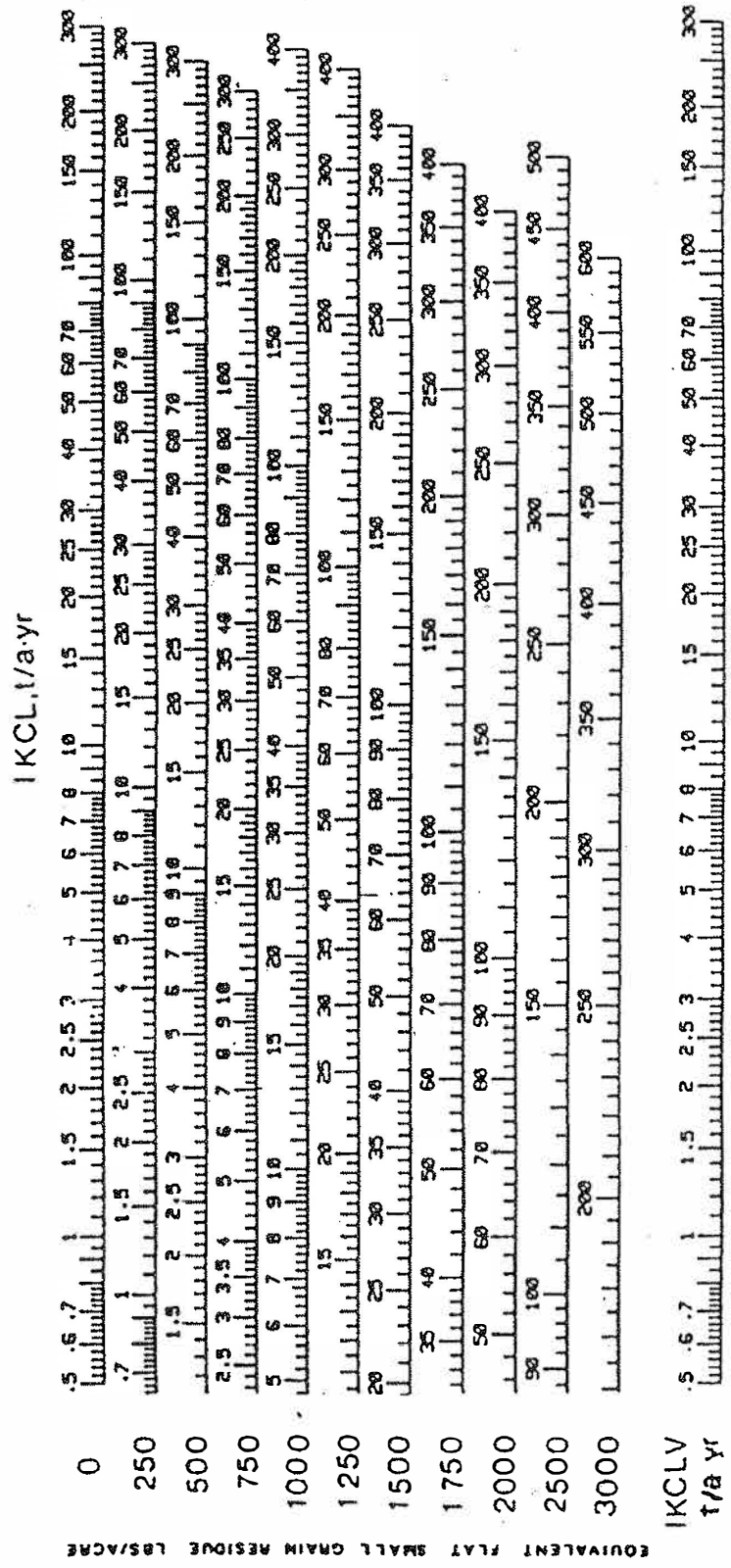

Figure 3.7.1-5 Revised wind erosion calculator scale for finding $E = f(I', K', C', L', V)$ as a function of E_3 and designated values of equivalent flat small grain residue (V) in lb/ac. The E value is determined by entering the graph on the left at the appropriate level of V and following it horizontally across to the value of E_3. A line vertically through the E_3 value will give the E value in either the bottom or top scale. [From the *Journal of Soil and Water Conservation*, Volume 38, p. 110–112, 1983 (Skidmore).]

Mitigation Techniques

For a given location, soil type, and slope position, the expected soil losses will vary with (1) the density and height of the vegetation cover, (2) the orientation of the field with respect to the predominant wind direction, and (3) the presence of wind barrier adjacent to bare fields. The greater the density and height of onsite vegetation, the lower the expected losses from wind erosion. By orienting the field so that the longest dimension lies perpendicular to the predominant wind direction, the emissions will also be reduced. Shelterbelt planting or hedgerows also reduce the width-of-field factor (L'), and so the expected wind erosion loss.

As a last resort, the soil surface could be watered during dry or windy weather to bind the soil particles and reduce wind erosion losses.

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5. Thornthwaite, C. W. 1931. Climates of North America according to a new classification. *Geograph. Rev.* 21:633-655.

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Chapter 4
Options for Modeling

Introduction

This chapter provides information on models available for evaluating the impacts Forest Service projects or activities have on air quality. The information is organized so that the reader can easily select a model for a particular project or activity. The information provided in this chapter assumes the reader has a working knowledge of models and their regulatory applications. Additional modeling guidance can be obtained from the *Guideline on Air Quality Models (Revised)* (EPA, 1993) or by contacting an EPA regional office or local air quality regulatory agency (see Appendix A).

This chapter first presents tables that are designed to help the reader determine how a source (such as wildfire or prescribed natural fire) can be characterized and what is the most appropriate model based on the source type, air quality impact to be evaluated, land use, terrain, and level of analysis. A description of the meteorological and climatological influences on the dispersion of pollutants follows. Next, a brief summary of each model, organized alphabetically, is provided. Lastly, a discussion of how to obtain the models is included.

Selection of a Model

The following pages contain two reference tables for selecting a model to quantify air quality impacts from Forest Service projects or activities. Tables 4-1 and 4-2 were designed to be used together to select a model for each source described in Chapter 3. Table 4-1 summarizes, by source, the project or activity producing the emissions, examples of each source, and the type of air quality impact to be evaluated. The right hand column recommends how each example of the source can be characterized: point, area, line, volume, or flare. Once a source is characterized, Table 4-2 is used to determine the most appropriate model for each air quality impact to be evaluated, considering the land use, terrain, and level of analysis desired.

The source types described in Table 4-1 are defined as follows:

- Point Source: A single, identifiable source of emissions that occupies a relatively small area and is confined by walls or similar structure up to the point of emissions (e.g., exhaust pipe)
- Area Source: An uncontained source whose emissions emanate from a plane (e.g., exposed soil area, broadcast burn)
- Volume Source: An uncontained source whose emissions are diluted into a volume of air (e.g., smoke plume, explosion cloud)
- Line Source: An uncontained source whose emissions emanate from a line, particularly those that are not properly

characterized by a series of point sources (e.g., roads, trails, fire lines).

- Flare Source: A point source that is heated to combustion temperatures at the point of emissions (e.g., campfire within concrete enclosure, gas burners)

The terrain types described in Table 4-2 are defined as follows:

- Flat Terrain: All terrain elevations are assumed to be at the elevation of the emission source.
- Simple Terrain: Receptor elevations that are less than or equal to the stack height for point sources (or the elevation of emissions for area, point, and line sources).
- Complex Terrain: Receptor elevations that are greater than or equal to the final plume height.

The levels of analysis described in Table 4-2 are defined as follows:

- Screening Analysis: A relatively simple analysis technique to determine if a given source is a threat to air quality. Usually involves minimal input requirements, and typically uses a worst-case set of representative (not actual) meteorological data. Produces conservative (higher than expected) results.
- Refined Analysis: A relatively detailed analytical technique that provides more detailed treatment of sources, terrain, and atmospheric processes (e.g., building downwash). Requires more detailed and precise input data, including the use of actual sequential hourly meteorological data from the vicinity of the source or impact area. Provides more specialized, and less conservative, concentration estimates.

Table 4-1
Source Characterization Chart

Emission Sources	Example Forest Service Projects or Activities	Source Examples	Source Types[a]					Air Quality Impacts
			P	A	L	V	F	
3.1 Wood Combustion								
3.1.1 Wildfire and Prescribed Natural Fire	Ecosystem Management Plans	Fire Area		X				Smoke Visibility
		Fire Line	X	X	X			
3.1.2 Prescribed Burning	Ecosystem Management Plans Timber Harvest Operations Campground Development Ski Area Development	Broadcast Burn		X				Smoke Visibility
		Pile Burn	X	X				
		Fire Line	X	X	X			
3.1.3 Other Open Burning (Wood Residue)	Campground Development Ski Area Development Ski Area Operation Firewood Sales Programs Recreation Management	Pile Burn	X	X				Smoke Visibility
3.1.4 Residential Fireplaces	Ski Area Operation Firewood Sales Programs Recreation Management	Chimney	X					Short-Range D/D[b] Long-Range D/D[b] Visibility
3.1.5 Residential Wood Stoves	Ski Area Operation Firewood Sales Programs Recreation Management	Chimney	X					Short-Range D/D[b] Long-Range D/D[b] Visibility

Table 4-1
Source Characterization Chart

Emission Sources	Example Forest Service Projects or Activities	Source Examples	Source Types[a] P	A	L	V	F	Air Quality Impacts
3.2 Fugitive Dust								
3.2.1 Vehicle Traffic on Unpaved Roads	Timber Harvest Operations Campground Development Road Construction Building Construction Ski Area Development Recreation Management Oil and Gas Leasing Mining Development and Operations	Dirt Roads	X	X	X	X		Short-Range D/D[b] Long-Range D/D[b] Visibility
		Dirt Staging Area	X	X	X	X		
		Dirt Parking Lot	X	X	X	X		
3.2.2 Vehicle Traffic on Paved Roads	Timber Harvest Operations Road Construction Building Construction Ski Area Development Ski Area Operation Recreation Management Oil and Gas Leasing Mining Development and Operations	Asphalt Roads	X	X	X	X		Short-Range D/D[b] Long-Range D/D[b] Visibility
		Paved Staging Area	X	X	X	X		
		Paved Parking Lot	X	X	X	X		
3.2.3 Heavy Construction Operations (Fugitive Dust)	Campground Development Oil and Gas Leasing	Excavation Area	X	X		X		Short-Range D/D[b] Long-Range D/D[b] Visibility
		Staging Area	X	X		X		
3.2.4 Aggregate Handling and Storage Piles	Road Construction Building Construction Ski Area Development Oil and Gas Leasing Mining Development and Operations	Aggregate Processing Site		X		X		Short-Range D/D[b] Long-Range D/D[b] Visibility
		Storage Piles		X		X		

Table 4-1
Source Characterization Chart

Emission Sources	Example Forest Service Projects or Activities	Source Examples	Source Types[a] P	A	L	V	F	Air Quality Impacts
3.3 Internal Combustion Engines (Exhaust)								
3.3.1 Gasoline and Diesel Industrial Engines (Stationary)	Timber Harvest Operations Road Construction Building Construction Ski Area Development Ski Area Operation Recreation Management Oil and Gas Leasing Mining Development and Operations	Exhaust Pipes	X	X				Short-Range D/D[b] Long-Range D/D[b] Visibility
3.3.2 Motor Vehicle Emissions	Timber Harvest Operations Campground Development Road Construction Building Construction Ski Area Development Ski Area Operation Oil and Gas Leasing	Roadways		X	X			Short-Range D/D[b] Long-Range D/D[b] Transportation
		Parking Lots		X				
		Staging Areas		X				
3.3.3 Large Diesel Engines (Stationary)	Oil and Gas Leasing Mining Development and Operations	Exhaust Pipes	X	X				Short-Range D/D[b] Long-Range D/D[b] Visiblity
3.4 Road Building								
3.4.1 Asphalt Paving	Campground Development Road Construction Ski Area Development	Asphalt Paver	X	X	X			Short-Range D/D[b] Long-Range D/D[b] Visibility
3.4.2 Asphaltic Concrete Plants	Road Construction	Concrete Processing Site	X	X		X		Short-Range D/D[b] Long-Range D/D[b] Visibility
		Hot Oil Heaters	X	X				

Table 4-1
Source Characterization Chart

Emission Sources	Example Forest Service Projects or Activities	Source Examples	Source Types[a]					Air Quality Impacts
			P	A	L	V	F	
3.5 Road Materials Processing								
3.5.1 Crushed Stone Processing	Road Construction	Screening	X	X		X		Short-Range D/D[b] Long-Range D/D[b] Visibility
		Crushing	X	X		X		
		Conveyor Transfer Point	X	X		X		
		Drilling	X	X		X		
		Truck Loading	X	X		X		
3.5.2 Sand and Gravel Processing	Road Construction	Screening	X	X		X		Short-Range D/D[b] Long-Range D/D[b] Visibility
		Crushing	X	X		X		
		Conveyor Drop Point	X	X		X		
		Storage Piles		X		X		
		Site Emissions During Inactivity		X		X		
3.5.3 Ore Crushing and Grinding	Mining Development and Operations	Ore Processing Site Emissions		X		X		Short-Range D/D[b] Long-Rane D/D[b] Visibility

Table 4-1
Source Characterization Chart

Emission Sources	Example Forest Service Projects or Activities	Source Examples	Source Types[a]					Air Quality Impacts
			P	A	L	V	F	
3.6 Oil and Gas Development								
3.6.1 Well Field Emissions	Oil and Gas Leasing	Drilling	X	X		X		Short-Range D/D[b] Long-Range D/D[b] Photochemical
		Waste Pits	X	X				
		Separators	X	X				
		Casing Heads	X	X				
		Glycol Dehydrators	X	X		X		
		Flares					X	
		Fugitive Losses		X		X		
3.6.2 Tank Farm Emissions	Oil and Gas Leasing	Tanks	X	X	X			Short-Range D/D[b] Long-Range D/D[b] Photochemical
3.7 Miscellaneous								
3.7.1 Wind Erosion on Bare or Vegetated Soil Areas	Ecosystem Management Plans Timber Harvest Operations Agricultural Operations	Vegetated Soil Area		X	X	X		Short-Range D/D[b] Long-Range D/D[b] Visibility
		Bare Soil Area		X	X	X		

[a]Source Type: P = Point, A = Area, L = Line, V = Volume, F = Flare
[b]D/D = Dispersion/deposition

Table 4-2
Model Selection Chart

Air Quality Impact	Land Use (Rural or Urban)	Terrain* (Flat, Simple, or Complex)	Level of Detail (Screening or Refined)	Model
Source Type: Point				
Short-Range Dispersion/Deposition	Both	All	Both	SHORTZ
	Both	All	Screening	SCREEN2
	Both	Complex	Refined	CTDMPLUS
	Both	Complex	Screening	CTSCREEN
	Both	Simple	Refined	ISC2
	Rural	Complex	Screening	COMPLEX 1
	Rural	Complex	Screening	COMPLEX 1/Valley Mode
	Rural	Simple	Refined	BLP
	Urban	Flat	Refined	PAL-DS
	-	All	Refined	RADM
Long-Range Dispersion/Deposition	Both	Simple	Screening	ISC2
	-	Complex	Refined	PUFF
	-	Flat	Refined	MESOPUFF II
Visibility	-	Both	Refined	ERT Visibility Model
	-	Both	Refined	PLUVUE II
	-	Both	Screening	VISCREEN
Photochemical	Urban	Flat	Refined	UAM
	-	Flat	Refined	RPM II

Table 4-2
Model Selection Chart

Source Type: Point (Continued)				
Smoke	Rural	Complex	Screening	WYNDvalley
	Rural	Flat	Screening	VSMOKE
	-	Complex	Refined	PUFF
	-	Flat	Screening	TSARS
	-	Flat	Screening	SASEM
Source Type: Area				
Short-Range	Both	All	Both	SHORTZ
	Both	All	Screening	SCREEN2
	Both	Simple	Refined	ISC2
	Urban	All	Refined	RADM
	Urban	Flat	Refined	PAL-DS
Long-Range	Both	Simple	Screening	ISC2
	-	Complex	Refined	PUFF
	-	Flat	Refined	MESOPUFF II
Visibility	Both	All	Refined	PLUVUE II
Photochemical	Both	Complex	Refined	EKMA
	Urban	Flat	Refined	UAM
	-	Flat	Refined	RPM II

Table 4-2
Model Selection Chart

Smoke	Rural	Complex	Screening	WYNDvalley
	Rural	Flat	Screening	VSMOKE
	-	Complex	Refined	PUFF
Source Type: Flare				
Short-Range	Both	All	Screening	SCREEN2
Source Type: Line				
Short-Range	Both	Simple	Refined	ISC2
	Rural	Simple	Refined	BLP
Long-Range	Both	Simple	Screening	ISC2
Transportation	Both	Simple	Refined	CALINE3
	Urban	Flat	Refined	PAL-DS
Smoke	-	Flat	Screening	SASEM
	-	Flat	Screening	TSARS

Table 4-2
Model Selection Chart

Source Type: Volume

Short-Range	Both	All	Screening	SCREEN2
	Both	Simple	Refined	ISC2
Long-Range	Both	Simple	Screening	ISC2
Photochemical	-	Flat	Refined	RPM-IV

*Simple terrain is defined as terrain that is lower in elevation than the top of the stack of the source. Complex terrain is defined as terrain exceeding the height of the stack being modeled.

Model Summaries

This section summarizes key features of EPA preferred, EPA alternative, and other air quality models that can be used for quantitative air quality analyses. Information is provided regarding the availability, approximate cost (as of 1990), and regulatory use of each model. EPA preferred models may be used without a formal demonstration of applicability provided that they satisfy the recommendations for regulatory use; not all options in the models are necessarily recommended for regulatory use. EPA alternative and other models may be considered on a case-by-case basis for individual regulatory applications. The models are listed by name in alphabetical order.

Many of these models have been subjected to a performance evaluation using comparisons with observed air quality data. A summary of such comparisons for models contained in this section is included in "A Survey of Statistical Measures of Model Performance and Accuracy for Several Air Quality Models," EPA-450/4-83-001. Several of the models described in this section have been subjected to evaluation exercises, including statistical performance tests recommended by the American Meteorological Society and peer scientific reviews. The EPA preferred models in this section have been selected on the basis of the results of the model evaluations, EPA's and the public's experience with the model, and the costs and resource requirements for use.

For EPA alternative and other air quality models, there are three separate conditions under which the models will normally be approved for use:

- If it can be demonstrated that the model produces concentration estimates equivalent to the estimates obtained using an EPA preferred model (for example, the maximum or second-highest concentration is within 2 percent of the estimate using the comparable preferred model)

- If a statistical performance evaluation has been conducted using measured air quality data, and the results of that evaluation indicate that the EPA alternative or other model performs better for the application than a comparable EPA preferred model

- If there is no EPA preferred model for the specific application but a refined model is needed to satisfy regulatory requirements

Any one of these three separate conditions may warrant use of these models.

Buoyant Line and Point Source Dispersion Model (BLP)

The Buoyant Line and Point Source Dispersion Model (BLP) is a Gaussian plume dispersion model designed to handle unique modeling problems associated with aluminum reduction plants and other industrial sources where plume rise and downwash effects from stationary line sources are important. For regulatory applications, BLP is an EPA preferred model for aluminum reduction plants with buoyant, elevated line sources; in rural areas; with transport distances less than 50 kilometers; in simple terrain; and with 1-hour to 1-year averaging times.

For other applications, BLP can be used if it can be demonstrated to give the same estimates as a recommended model for the same application, and will subsequently be executed in that mode.

BLP may be used to model primary pollutants. This model does not treat settling and deposition. The building downwash algorithm of Schulman and Scire (1980) is used.

BLP can be used on a case-by-case basis with specific options not available in a recommended model if it can be demonstrated, using the criteria in Section 3.2 of the *Guideline on Air Quality Models (Revised)*, that the model is more appropriate for a specific application.

The computer code for BLP is available on magnetic tape from NTIS (NTIS No. PB 81-164642).

California Line Source Dispersion Model (CALINE3)

The California Line Source Dispersion Model (CALINE3) can be used to estimate the concentrations of nonreactive pollutants from highway traffic. This steady-state Gaussian model can be applied to determine air pollution concentrations at receptor locations downwind of "at-grade," "fill," "bridge," and "cut section" highways located in relatively uncomplicated terrain. The model is applicable for any wind direction, highway orientation, and receptor location. The model has adjustments for averaging time and surface roughness and can handle up to 20 links and 20 receptors. It also contains an algorithm for deposition and settling velocity so that particulate concentrations can be predicted.

CALINE3 is an EPA preferred model appropriate for highway (line) sources, urban or rural areas, simple terrain, transport distances less than 50 kilometers, and 1-hour to 24-hour averaging times.

The CALINE3 model computer tape is available from NTIS as PB 80-220833. The model is also available from the California Department of Transportation (manual free of charge and approximately $50 for the computer tape). Requests should be directed to:

Mr. Marlin Beckwith
Chief, Office of Computer Systems
California Department of Transportation
1120 N Street
Sacramento, CA 95814

CAL-PUFF

As recommended by the Interagency Workgroup on Air Quality Modeling (IWAQM), CAL-PUFF is the proposed Phase 2 model to be used in long-range transport modeling applications. Because the model is under development, a model summary is not available at this time. For additional information, please contact Joe Scire at:

Sigma Research
Boston, Massachusetts
(508) 371-4270

COMPLEX 1

COMPLEX 1 is a straight-line, steady-state Gaussian plume dispersion model designed to evaluate the concentrations of nonreactive pollutants emitted from point sources in complex terrain. Model features include stack tip downwash, single or multiple point sources, buoyant plume rise and buoyancy-induced dispersion, separation of point sources, and adjustments for dispersion in complex terrain. Horizontal plume spreading is assumed to be uniform across a 22.5-degree sector. COMPLEX 1 cannot evaluate emissions from area, line, or volume sources, nor can it evaluate building- or terrain-induced wake effects on dispersion. COMPLEX 1 can operate in a screening mode or in a refined mode using actual hourly sequential meteorological data. The screening mode, COMPLEX 1/Valley Mode, uses meteorological conditions used in the VALLEY model. This model is based on 6 hours of impact out of 24 hours under F stability and a wind speed of 2.5 meters per second.

The model code is available on the SCRAM BBS and also from the NTIS.

Complex Terrain Dispersion Model Plus Algorithms for Unstable Situations (CTDMPLUS)

The Complex Terrain Dispersion Model Plus Algorithms for Unstable Situations (CTDMPLUS) is a refined point source Gaussian air quality model for use in all stability conditions for complex terrain applications. It contains, in its entirety, the technology of CTDM for stable and neutral conditions. However, CTDMPLUS can also simulate unstable daytime conditions, and it has a number of additional capabilities for improved user friendliness. Its use of meteorological data and terrain information is different from other EPA models; considerable detail for both types of input data is required and is supplied by preprocessors specifically designed for CTDMPLUS. CTDMPLUS requires the parameterization of individual hill shapes using the terrain preprocessor and the association of each model receptor with a particular hill.

CTDMPLUS is an EPA preferred model appropriate for elevated point sources, terrain elevations above stack top, rural or urban areas, transport distances less than 50 kilometers, and 1-hour to annual averaging times when used with a post-processor program.

CTDMPLUS may be used to model nonreactive, primary pollutants.

This model code is available on the Support Center for Regulatory Air Models BBS and also from the NTIS.

CTDMPLUS Screening Mode (CTSCREEN)

The CTDMPLUS Screening Mode (CTSCREEN) is a screening-level model that can be used to obtain conservative (safely above those of refined models), yet realistic, impact estimates for stationary sources. CTSCREEN is the same model as CTDMPLUS except that CTSCREEN does not use actual meteorological data.

This model code is available on the Support Center for Regulatory Air Models Bulletin Board System and also from the NTIS.

ERT Visibility Model

The ERT Visibility Model is a Gaussian dispersion model designed to estimate visibility impairment for arbitrary lines of sight due to isolated point source emissions by simulating gas-to-particle conversion, dry deposition, NO to NO_2 conversion, and linear radiative transfer. The model simulates optical activity of sulfate, nitrate (derived from SO_2 and NO_x emissions), primary TSP, and NO_2.

The ERT Visibility Model, an alternative model, may be used on a case-by-case basis. There is no specific recommendation for its use at the present time.

The user's guide and model code are available from:

Mr. David W. Heinhold, CCM
Manager, Air Quality Studies
ENSR Consulting and Engineering
35 Nagog Park
Acton, MA 01720
Phone: 508/635-9500
Fax: 508/635-9180

Industrial Source Complex Model (ISC2)

The Industrial Source Complex Model (ISC2) is a steady-state Gaussian plume model that can be used to assess pollutant concentrations from a wide variety of sources associated with an industrial source complex. This model can account for the following: settling and dry deposition of particles; downwash; area, line, and volume sources; plume rise as a function of downwind distance; separation of point sources; and limited terrain adjustment. The model operates in both long-term and short-term modes. ISC2 may be used to model primary pollutants and continuous releases of toxic and hazardous waste pollutants. Settling and deposition are treated. ISC2 is an EPA preferred model appropriate for industrial source complexes, rural or urban areas, flat or rolling terrain, transport distances less than 50

kilometers, 1-hour to annual averaging times, and continuous toxic air emissions. ISC2 may also be used as a screening tool to predict long-range transport of pollutants.

The model code is available on the Support Center for Regulatory Air Models (SCRAM) BBS (see "Where to Get Models," p. 4-21) and also from the NTIS.

Mesoscale Puff Model (MESOPUFF II)

The Mesoscale Puff Model (MESOPUFF II) is a short-term, regional-scale Gaussian puff superposition model designed to calculate concentrations of up to five pollutant species: SO_2, sulfate (SO_4), NO_x, nitric acid (HNO_3), and nitrate (NO_3). Transport, puff growth, chemical transformation, and wet and dry deposition are accounted for in the model.

An alternative model, MESOPUFF II may be used on a case-by-case basis. There is no specific recommendation for its use at the present time.

This model code is available on the SCRAM BBS and also from the NTIS.

Plume Visibility Model (PLUVUE II)

The Plume Visibility Model (PLUVUE II) is a Gaussian plume model used for estimating visual range reduction and atmospheric discoloration caused by plumes resulting from the emissions of particles, nitrogen oxides, and sulfur oxides from a single emission source. PLUVUE II predicts the transport, dispersion, chemical reactions, optical effects, and surface deposition of point or area source emissions.

PLUVUE II is an alternative model that may be used on a case-by-case basis. When applying PLUVUE II to assess the visual impact of a plume, the following precautions should be taken to avoid the possibility of error:

- Treat the optical effects of nitrogen dioxide (NO_2) and particles separately as well as together to avoid cancellation of NO_2 absorption with particle scattering.
- Examine the visual impact of the plume at 0.1 (or 0), 0.5, and 1.0 times the expected level of particulate matter in the background air.
- Examine the visual impact of the plume over the full range of observer–plume–sun angles.

The model code is available on the SCRAM BBS and also from the NTIS.

Point, Area, Line Source Algorithm (PAL-DS)

PAL-DS is an acronym for this point, area, and line source algorithm and is a method of estimating short-term dispersion using Gaussian-plume steady-state assumptions. The algorithm can be used for estimating concentrations of nonreactive pollutants at 99 receptors for averaging times of 1 to 24 hours and for a limited number of point, area, and line sources (99 of each type). This algorithm is not intended for application to entire urban areas; rather, it is intended to assess the impact on air quality, on scales of tens to hundreds of meters, of portions of urban areas such as shopping centers, large parking areas, and airports. Level terrain is assumed. The Gaussian point source equation estimates concentrations from point sources after determining the effective height of emission and the upwind and crosswind distance of the source from the receptor. Numerical integration of the Gaussian point source equation is used to determine concentrations from the four types of line sources. Subroutines are included that estimate concentrations for multiple lane line and curved path sources, special line sources (line sources with end points at different heights above the ground), and special curved path sources. Integration over the area source, which includes edge effects from the source region, is done by considering finite line sources perpendicular to the wind at intervals upwind from the receptor. The crosswind integration is done analytically; integration upwind is done numerically by successive approximations.

The PAL-DS model uses Gaussian plume-type diffusion-deposition algorithms based on analytical solutions of a gradient-transfer model. The PAL-DS model can treat deposition of both gaseous and suspended particulate pollutants in the plume because gravitational settling and dry deposition of the particles are explicitly accounted for. The analytical diffusion-deposition expressions listed in the user's guide are easy to apply and, in the limit when pollutant settling and deposition velocities are zero, they reduce to the usual Gaussian plume diffusion algorithms in the PAL model.

An alternative model, PAL-DS can be used on a case-by-case basis in lieu of a preferred model if it can be demonstrated, using the criteria in Section 3.2 of the *Guideline on Air Quality Models (Revised)*, that PAL-DS is more appropriate for the specific application. In this case the model options/modes that are most appropriate for the application should be used.

PAL-DS can be used if it can be demonstrated to estimate concentrations equivalent to those provided by the preferred model for a given application. PAL-DS must be executed in the equivalent mode.

The computer code is available on magnetic tape from the NTIS.

PUFF

PUFF is a long-range Gaussian puff dispersion model that can be used to predict forest fire smoke emissions, transport, dispersion, and wet and dry deposition. It can be used as a decision-making tool for smoke managers to avoid intrusions into population centers, over highways, and into or over Class I wilderness areas. PUFF can be used to simulate emissions

of PM, CO, and heat plumes. Like the Tiered Smoke Air Recovery System (TSARs), PUFF uses Emissions Production Model (EPM) parameters as model inputs and can simulate plumes from multiple burns at different elevations. The model has a built-in digitized terrain map for Oregon, Washington, Montana, Idaho, Wyoming, northern California, northern Nevada, northern Utah, northwestern Colorado, and southern British Columbia and can graphically display smoke trajectories.

The model is currently being modified to predict ground-level pollutant concentrations.

The model code is available from:

Dr. Halstead Harrison
WYNDsoft, Inc.
6333 77th Avenue SE
Mercer Island, WA 98040
(206) 232-1819

Random-Walk Advection and Dispersion Model (RADM)

The Random-Walk Advection and Dispersion Model (RADM) is a Lagrangian dispersion model that uses the random-walk method to simulate atmospheric dispersion. The technical procedure involves tracking tracer particles having a given mass through advection by the mean wind and diffusion by the random motions of atmospheric turbulence. Turbulent movement is calculated by determining the probability distribution of particle movement for a user-defined time step. A random number between 0 and 1 is then computed to determine the distance of particle movement according to the probability distribution. A large number of particles is used to statistically represent the distribution of pollutant mass. Concentrations are calculated by summing the mass in a volume around the receptor of interest and dividing the total mass by the volume. Concentrations can be calculated for any averaging time. RADM is applicable to point and area sources. RADM may be used to model inert gases and particles and pollutants with exponential decay or formation rates.

RADM is an alternative model and may be used on a case-by-case basis. There is no specific recommendation at the present time.

A magnetic tape of the computer code and the user's manual are available for a cost of $440.00 from:

Mr. C. James Olsten
Dames & Moore
445 South Figueroa Street, Suite 3500
Los Angeles, CA 90071-1665

Reactive Plume Model (RPM-IV)

The Reactive Plume Model (RPM-IV) is a computerized model used for estimating short-term concentrations of primary and secondary pollutants resulting from point or area source emissions. The model is capable of simulating the complex interaction of plume dispersion and nonlinear photochemistry. The model has two main features: the horizontal resolution within the plume, which offers a more realistic treatment of the entrainment process, and its flexibility with regard to choices of chemical kinetic mechanisms. RPM-IV uses the Carbon Bond Mechanism (CBM-II) to simulate 35 species (68 reactions). These include NO, NO_2, O_3, SO_2, $SO_4^=$, five categories of reactive hydrocarbons, secondary nitrogen compounds, organic aerosols, and radical species.

As an alternative model, RPM-IV may be used on a case-by-case basis. There is no specific recommendation for this model at the present time.

RPM-IV is available from the NTIS ($16.95 for paper copy; $5.95 on microfiche). The accession number for the computer tape for RPM-IV is PB83-154898, and the cost is $460.00.

Simple Approach Smoke Estimation Model (SASEM)

The Simple Approach Smoke Estimation Model (SASEM) is a straight-line Gaussian plume dispersion model designed as a screening tool to predict maximum particulate concentrations and visual impacts from prescribed fires. SASEM simulates emissions, transport, dispersion, and optical effects of any inert pollutant over flat terrain. Emissions are calculated from fire line intensity, average fuel loading, and the area and duration of the burn. This model is suitable for rangeland and slash pile fires in the western United States. The emission factors contained in the model are for the palmetto-gallberry shrub type. Minimal data input and expertise are required to use this model; this allows fire managers to make fire management decisions quickly.

The model code is available from:

Mike Sestak
Bureau of Land Management
Cheyenne, WY
(303) 221-4873

SCREEN2

SCREEN2 is an interactive PC-based model that was developed as a simple tool for assessing the impacts of inert, nonreactive pollutants emitted from single stationary sources. The assumptions used in SCREEN2 are conservative in order to provide reasonable assurance that maximum concentrations are not underestimated.

SCREEN2 is a Gaussian plume dispersion model that can predict maximum 1-hour ambient concentrations from point (stack), flare, area, or volume sources. The model uses 54

combinations of default 1-hour screening meteorological conditions. The user can select either discrete receptor distances or a range of receptor distances to be evaluated. SCREEN2 can model concentrations in either flat, simple, or complex terrain (complex terrain is defined as terrain higher than the modeled stack top). The model allows the user to select either rural or urban dispersion coefficients. For point sources, SCREEN2 can also account for building downwash, a condition where the aerodynamic wake of a building near the stack affects the dispersion of the emission plume.

The model code is available on the SCRAM BBS and also from the NTIS.

SHORTZ

SHORTZ uses the steady-state bivariate Gaussian plume formulation for both urban and rural areas in flat or complex terrain to calculate ground-level ambient air concentrations. SHORTZ may be used to model primary pollutants. Settling and deposition of particulates are treated. It can calculate multiple-hour (1-hour, 2-hour, 3-hour, etc.) average concentrations that are a result of emissions from stacks, buildings, and area sources for up to 300 arbitrarily placed sources. The output consists of the total concentration at each receptor that is due to emissions from each user-specified source or group of sources, including all sources. If the option for gravitational settling is invoked, analysis cannot be accomplished in complex terrain without mass continuity being violated.

SHORTZ can be used if it can be demonstrated to estimate concentrations equivalent to those provided by the preferred model for a given application. SHORTZ must be executed in the equivalent mode.

SHORTZ can be used on a case-by-case basis in lieu of a preferred model if it can be demonstrated, using the criteria in Section 3.2 of the *Guideline on Air Quality Models (Revised)*, that SHORTZ is more appropriate for the specific application. In this case the model options/modes that are most appropriate for the application should be used.

The computer code is available on magnetic tape from the NTIS.

Smoke Dispersion and Plume Visibility Model (VSMOKE)

The Smoke Dispersion and Plume Visibility Model (VSMOKE) is a single-layer, straight-line Gaussian plume dispersion model that can be used to predict PM and CO impacts from slash piles or broadcast burns. VSMOKE is a rural, flat-terrain screening model that treats point or area sources located at ground level only. This model is currently being developed by the Forest Service as a tool to evaluate potential impacts from forestry burning operations in simple terrain anywhere in the United States. VSMOKE computes concentrations and visibility impacts at 31 logarithmically spaced receptors at distances ranging from 100 meters to 100 kilometers.

The model code is available from:

Leonidas Lavdas
USDA Forest Service
Southeastern Forest Experiment Station
Route 1, Box 182A
Dry Branch, GA 31020

Tiered Smoke Air Resources System (TSARS)

A modification of SASEM, the Tiered Smoke Air Resources System (TSARS) is a straight-line Gaussian plume dispersion model with optical effects. TSARS differs from SASEM in that it includes emission factors for activity fuels (slash) in the Pacific Northwest. It is designed to estimate particulate matter emissions from fire lines and slash piles. Model inputs require EPM parameters of area burned, species, fuel loadings by size class, fuel moisture, and weather data (wind speed) for specific burn units. Like SASEM, this model is designed as a quick response smoke management tool. It is particularly suited for broadcast burns in Oregon, Washington, and northern California.

The model code is available from:

Mike Sestak
Bureau of Land Management
Cheyenne, Wyoming
(303) 221-4873

Urban Airshed Model (UAM)

The Urban Airshed Model (UAM) is an urban-scale, three-dimensional, grid-type numerical simulation model. The model incorporates a condensed photochemical kinetics mechanism for urban atmospheres. The UAM is designed for computing O_3 concentrations under short-term, episodic conditions lasting 1 or 2 days resulting from emissions of NO_x, VOCs, and CO. The model treats urban VOC emissions as their carbon-bond surrogates.

UAM is an EPA-preferred model appropriate for urban areas having significant ozone attainment problems and 1-hour averaging times.

UAM has many options, but no specific recommendations can be made at this time on all options. The reviewing agency should be consulted regarding selection of options to be used in regulatory applications.

The model code is available on the Support Center for Regulatory Air Models BBS and also from the NTIS.

Visual Impact Screening Model (VISCREEN)

The Visual Impact Screening Model (VISCREEN) is an interactive PC-based model that was developed as a screening tool for performing Level 1 and Level 2 calculations of potential plume visual impacts, especially in PSD Class I areas where visibility is a protected value. The model estimates the color difference and the contrast of a plume against its viewing background. VISCREEN calculates these parameters for single point sources emitting particulates, NO, NO_2, soot, and primary sulfate. The results of the modeling are compared to criteria established for both parameters. Because the model was designed to perform screening calculations, the potential plume visual impacts are overpredicted. Therefore, VISCREEN calculates larger plume visual impacts, for the same input specifications, than do more sophisticated models such as PLUVUE II. VISCREEN does not assess regional haze.

VISCREEN can be applied in two successive levels of assessing potential plume visual impacts (Levels 1 and 2) without the need for extensive input specification. Level 1 screening assumes default particle size and density and worst-case meteorological conditions of F stability and wind speed of 1.0 meter per second (m/s). Level 2 screening allows user-specified particle size and density and user-specified worst-day meteorological conditions (determined using actual meteorological data). If the Level 1 or Level 2 screening calculations demonstrate that the criteria are exceeded, a more detailed plume visual impact analysis (Level 3) is performed using a more sophisticated model.

VISCREEN is designed to operate on IBM-compatible computers. The model operates with 256 KB of memory. It uses a math coprocessor, if installed, with substantial improvement in execution speed.

The model code is available on the SCRAM BBS and from the NTIS.

WYNDvalley Model

WYNDvalley 3.11 is a multilayer (up to five vertical layers), three-dimensional Eulerian grid dispersion model that permits users flexibility in defining borders around the areas to be modeled, the boundary conditions at these borders, the intensities and locations of emissions sources, and the winds and diffusivities that affect the dispersion of atmospheric pollutants. WYNDvalley may be used to model any inert pollutant. The model's output includes gridded contour plots of pollutant concentrations for the highest brief episodes (during any single time step), the highest and second-highest 24-hour averages, averaged dry and wet deposition fluxes, and a colored "movie" showing evolving dispersal of pollutant concentrations, together with temporal plots of the concentrations at specified receptor sites and statistical inference of the probabilities that standards will be exceeded at those sites. WYNDvalley is implemented on IBM®-compatible microcomputers, with interactive data input and color graphics display.

WYNDvalley is an alternative model that may be used on a case-by-case basis to estimate concentrations during valley stagnation periods of 24 hours or longer.

Copies of the user's guide and the executable model computer codes are available at a cost of $295.00 from:

WYNDsoft, Incorporated
6333 77th Avenue SE
Mercer Island, WA 98040
Phone: (206) 232-1819

Where to Get Models

National Technical Information Service (NTIS)

Most models and user's documentation presented in this chapter are available from the National Technical Information Service (NTIS), a branch of the U.S. Department of Commerce. NTIS is the central distribution center for the sale of U.S.- and foreign-government-sponsored research, development, engineering, and business reports. Documentation and code for selected models can be obtained by contacting the following:

Computer Products
National Technical Information Service (NTIS)
U.S. Department of Commerce
Springfield, VA 22161
Phone: (703) 487-4650

Technology Transfer Network (TTN)

Model codes and selected abridged user's guides are also available from the EPA Office of Air Quality Planning and Standards Technology Transfer Network (TTN). The TTN is an electronic bulletin board system that is used to facilitate communication and provide information to all persons involved in air pollution control and prevention activities. To access the TTN the following computer equipment is needed:

- Computer
- 1200-, 2400-, or 9600-baud modem (9600 baud recommended)
- Communication software

Once the computer hardware is set up, the communications program must be installed and set up with the following parameters:

Telephone number:	(919) 541-5742 (1200/2400-baud modem) (919) 541-1447 (9600-baud modem)
Data Bits:	8
Parity:	None
Stop Bit:	1
Emulation:	VT100 (Optional; required to display PC graphics and colors if your system supports it)
Duplex:	Full

With these settings installed on the computer system, the TTN can be accessed. The only cost for using the TTN is the telecommunication charges.

Most of the air quality models discussed in this section are available from the Support Center for Regulatory Air Models (SCRAM) bulletin board system on the TTN. The SCRAM BBS provides current information, computer source code, and documentation for most of EPA's air quality models. It includes updates, corrections, and new regulatory requirements for these models. The SCRAM BBS also supplies National Weather Service meteorological data. Announcements and new information are summarized in the "Alerts" area of the bulletin board, allowing the user to quickly review the latest developments.

Chapter 5
Aerometric Monitoring

Introduction and Purpose of Monitoring

The purpose of this chapter is to address the need for aerometric monitoring in the NEPA process and to describe some of the monitoring technologies that are currently available for different pollutants or groups of pollutants.

Ambient Monitoring Requirements in NEPA

Air pollution is mentioned in NEPA as a potential adverse environmental impact, but neither NEPA nor the CEQ guidelines are specific about the requirements for ambient air monitoring. Nevertheless, ambient monitoring might be part of the NEPA process at least three points:

- As a basis for making a decision
- In the assessment of impacts
- In the record of decision

Each of these points is discussed below.

As a Basis for Making a Decision

Historical ambient monitoring data could be used in some limited circumstances as a basis for a making a decision about a project's future impacts. For example, if historical ambient monitoring data show that violations of the air-quality-related values (AQRV) thresholds or ambient air quality standards are occurring under existing conditions, it would be reasonable to project that even higher impacts would occur following implementation of the project (this depends on emissions and mitigation methods).

However, caution must be exercised in the use of ambient monitoring data in the decision-making process. CEQ regulations stipulate that if the environmental effects of an agency's proposed action are unknown, the agency may not determine that the action will not significantly affect the environment by relying solely on information to be gathered in the future (such as monitoring results) (Fogelman, 1990; p. 91). Furthermore, it explicitly points out that an "agency may not establish a monitoring program to take the place of an informed decision regarding an action's environmental effects." If an agency proposes to discontinue the intended action only after an unacceptable monitoring result is detected, it may be interpreted that the agency proceeded without full knowledge of the action's environmental effects (Fogleman, 1990; p. 91).

To Assess Potential Violations

The second area that may involve monitoring is the assessment of potential violations. If the project has the potential to violate federal, state, or local environmental protection laws (for example, NAAQS), the potential violation must be addressed in the EA or EIS through modeling or other predictive means.

Even if modeling is performed and the proposed action is shown to produce air concentrations that are less than the applicable standards, the project is not necessarily insignificant. On the contrary, the environmental effects of actions within the published standards might still be significant (Fogleman, 1990). Monitoring results, therefore, might be used to augment the predictive modeling results to demonstrate whether a project should be considered significant.

In the Record of Decision

The third area of the NEPA process that may involve monitoring is the record of decision. Section 1505.2(c) of the CEQ regulations (Fogelman, 1990) discusses the record of decision in cases requiring EISs and specifies that a monitoring and enforcement program shall be adopted and summarized where applicable for any mitigation. In the case of the Forest Service, this could include long-term meteorological monitoring. Section 1505.3 states that agencies may provide for monitoring to ensure that their decisions are carried out and should do so in important cases.

Other Uses for Ambient Monitoring

In the preparation of an EA or EIS, the typical reasons for performing ambient air quality monitoring include the following:

- To assess the background levels of air pollutants. This is needed to add to the project-related increases in air concentrations in determining the total impacts.
- To assess changes in ambient air quality following development of a proposed project. This could also be a condition set forth in the record of decision.
- To assess the background meteorological conditions prior to modeling. Again, this information would be used in the modeling process to determine total project-related impacts.
- To validate the results of the air dispersion modeling analysis.
- To provide a database for research evaluation of effects; urban, land-use, and transportation planning; and the development and evaluation of abatement strategies.
- To activate emergency control procedures that prevent or alleviate air pollution episodes.

Getting Started

Because monitoring is time consuming and expensive, alternatives to monitoring should be considered in the NEPA process. The most common means of predicting the environmental impacts of a proposed action is modeling (discussed in Chapter 4). In some circumstances, historical air quality monitoring data might be used to deduce the future impacts of a proposed action. Existing data might be obtained from federal, state, or local agencies. These agencies are the primary repository for such data and should be consulted before a monitoring program is undertaken or time is spent to obtain existing data.

In some instances the level of monitoring effort may be minimal. When precision and accuracy levels of a particular monitoring technique are not important and the goal of monitoring is solely qualitative then simple screening monitoring techniques can be applied. However if the goal is representative, reproducible and defensible data then the level of monitoring needs to be increased. For example if a proposed Forest Service action impacts a Class I area, it is recommended that the agency follow the Ambient Monitoring Guidelines for Prevention of Significant Deterioration (PSD) (U.S. EPA, 1987) or Quality Assurance handbook for Air Pollution Measurement Systems Vol. 1, 2, 4 (U.S. EPA, 1976). In these instances the recommendation is to use EPA reference or equivalent methods for monitoring criteria pollutants. In all monitoring situations, the methodology should be defensible. The following discussions are based on these two references.

Pre-Monitoring Considerations

Before a monitoring network can be designed, there are considerations that will have bearing on the monitoring network.

Monitoring Objectives and Spatial Scales

The goal in siting monitors is to match the spatial scale represented by the sample of monitored air with the spatial scale most appropriate for the monitoring objective. The following representative measurement scales are of most interest:

- Microscale–concentrations in air volumes with dimensions ranging from a few meters to about 100 meters.
- Middle scale–concentrations typical of areas up to several city blocks with dimensions ranging from about 100 meters to 0.5 km.
- Neighborhood scale–concentrations within an extended area of the city that has relatively uniform land uses with dimensions ranging from 0.5 to 4 km.
- Urban scale–overall citywide concentrations with dimensions of about 4 to 50 km. This scale usually requires more than one site for definition.

- Regional scale–usually concentrations measured in a rural area of reasonably homogenous geography that extends from tens to hundreds of km.

- National and global scales–concentrations characterizing the nation and/or the globe as a whole.

Representative Sampling

Ensuring the collection of a representative air quality sample depends on the following factors:

- Locating the sampling site and determining that the network size is consistent with the monitoring objectives

- Determining the restraints on the sampling site that are imposed by meteorology

- Determining the restraints on the sampling site that are imposed by local topography, emission sources, and physical constraints

- Planning sampling schedules that are consistent with the monitoring objectives

Site Location

In designing an air quality monitoring program, four criteria should be considered either separately or in combination for site location, depending on the sampling objective. The monitoring sites should be oriented to measure the following:

- The impacts of known pollutant emission categories on air quality

- The population density relative to receptor-dose levels, both short- and long-term

- The impacts of known pollutant emission sources (area and point) on air quality

- The representative areawide air quality

To select locations according to these criteria, it is necessary to have detailed information on the location of sources of emissions, the geographical variability of ambient pollutant concentrations, the meteorological conditions, and the population density. Therefore, the selection of the number, locations, and types of sampling stations is a complex process that defies a purely objective solution. Furthermore, the variability of sources and their intensities, terrains, meteorological conditions, and demographic features requires that each network be developed individually. Thus, selection of the network will be the result of subjective judgments based on available evidence and on the experience of the decision team.

The Agency could use the screening procedure or refined model estimates to determine the general location(s) of the maximum air quality concentrations. This modeling will also estimate the spatial variability of the pollutant. Monitoring should then be conducted in or as close to these maximum impact areas. Generally, one to four sites would cover most situations in multisource settings. For remote areas in which the permit-granting authority has determined that there are no significant existing sources, a minimum number of monitors would be needed (one, or probably two at the most). For new sources in these remote areas, as opposed to modifications, some concessions will be made on the locations of these monitors. Because the maximum impact from these new sources would be in remote areas, the monitors may be located, based on convenience or accessibility, near the proposed new source rather than near the maximum impact area because the existing air quality would be essentially the same in both areas. However, the maximum impact area is still the preferred location.

The sampling site selection process involves considerations of economic, logistic, atmospheric, and pollutant reaction factors in addition to the motivation for and the objective of the sampling program. None of the factors stands alone. Each is dependent in part on the others. However, the objective of the sampling program must be clearly defined before the selection process can be initiated, and the initial definition of priorities may have to be reevaluated after consideration of the remaining factors and before the final locations are chosen.

Economic Considerations. The economic considerations are rather clearly defined. The amount of money required for data gathering (instrumentation, installation, maintenance, and data retrieval), data analysis, quality assurance, and data interpretation must be balanced against the available monies (current and projected) and the cost-benefits of additional or relocated sampling sites.

Logistical Problems. The logistical problems involve the means of obtaining, analyzing, and interpreting the data. Can the current staff manage the proposed system, or are more or fewer people needed to accomplish the tasks? Is the derived information necessary on a real-time basis, or can several weeks pass before it is available?

Atmospheric Problems. The atmospheric problems pertain to definitions of the spatial and temporal variabilities of the pollutants and their transport. The effects of buildings, terrain, and heat sources or sinks on the air trajectories can produce local anomalies of excessive pollutant concentrations. Wind velocity, wind shear, and atmospheric stability can greatly influence the dispersal of pollutants.

Pollutant Considerations. A sampling site or an array of sites for one pollutant may be inappropriate for another pollutant species because of the configuration of sources, the local meteorology, or the terrain. Pollutants undergo changes in their compositions between their emission and their detection; therefore, the impact of that change on the measuring system should be considered. Atmospheric chemical reactions, such as the production of O_3 in the presence of NO_x and hydrocarbons, and the time delay between the emission of NO_x and hydrocarbons and detection of peak O_3 values, may require either a sampling network for the precursors of O_3 and/or a different network for the actual O_3 measurement.

Summary. While the interactions of the factors identified above are complex, the site selection problems can be resolved. Experience in the operation of air quality measurement systems, estimates of air quality, field and theoretical studies of atmospheric diffusion, and considerations of atmospheric chemistry and air pollution effects can play an important role in selection of the optimum sampling site for obtaining data representative of the monitoring objectives.

Meteorological Restraints

Meteorology must be considered in determining not only the geographical location of a monitoring site but also such factors as the height, direction, and extension of sampling probes. Meteorological parameters having the greatest influence on the dispersion of pollutants are the direction, speed, and variation of the wind, as well as the atmospheric stability and lapse rate.

Wind direction indicates the general movement of pollutants in the atmosphere. Review of available data can indicate mean wind direction in the vicinity of the major sources of emissions.

The wind speed affects both the travel time from the source to the receptor and the dilution of polluted air in the downwind direction.

A useful way of displaying wind data is a wind rose diagram constructed to show the distribution of wind speeds and directions. Data from which wind rose diagrams can be constructed are available in tabulated form through the National Climatic Data Center of the NOAA:

National Climatic Data Center
Federal Building
Asheville, North Carolina 28801-2696
(704) CLIMATE

Topographical Restraints

Both the transport and the diffusion of air pollutants are complicated by topographical features. Minor topographical features may exert small influences; major features, such as deep river valleys or mountain ranges, may affect large areas. Before final site selection, review the topography of the area to ensure that the purpose of monitoring at that site will not be adversely affected.

Land use and topographical characteristics of specific areas can be determined from land-use maps and U.S. Geological Survey (USGS) maps.

The final placement of the monitor at a selected site depends on physical obstructions and activities in the immediate area; the accessibility and availability of utilities and other support facilities; and correlations with the defined purpose of the specific monitor and the monitor design. Because obstructions such as trees and fences can significantly alter the air flow,

monitors should be placed away from such obstructions. It is important for air flow around the monitor to be representative of the general air flow in the area to prevent a sampling bias.

Considerations after Site Selection

Environment Control

A proper sampling environment demands control of all physical parameters external to the samples that might affect sample stability, chemical reactions within the sampler, or the function of sampler components. The important parameters to be controlled are instrument vibration, light, electrical voltage, temperature, and humidity. How and to what extent these parameters can be controlled is discussed in Quality Assurance Handbook for Air Pollution Measurement Systems, Volume 2.

Placement of Probes and Manifolds

Probes and manifolds must be placed to avoid introducing bias to the sample. Important considerations are probe height above the ground, probe length (for horizontal probes), and physical influences near the probe. Following are some general guidelines for probe and manifold placement:

- Probes should not be placed next to air outlets such as exhaust fan openings.
- Horizontal probes must extend beyond building overhangs.
- Probes should not be near physical obstructions, such as chimneys, that can affect the air flow in the vicinity of the probe.
- The height of the probe above the ground depends on the pollutant being measured.

Monitoring Technologies

Previous chapters discussed the emission source types that result from various Forest Service activities. Figure 5-1 shows the pollutants and pollutant groups emitted by Forest Service projects and activities. Once the pollutant or parameter of interest is identified, Table 5-1 can be consulted to determine the appropriate monitoring technology or device associated with each pollutant. The various monitoring technologies identified in Table 5-1 are discussed below. Further information on these monitoring technologies can be found in: *Methods of Air Sampling and Analysis*, James P. Lodge, Jr. Editor, Lewis Publishers, Inc., 1989; *Quality Assurance Handbook for Air Pollution Measurement Systems, Volume 2*, EPA, 1976; *Compendium of Methods for the Determination of Toxic Organic Compounds in Ambient Air*, Document number EPA-600/4-84-041, EPA, April, 1984.

Table 5-1
Parameter and Associated Levels of Monitoring

Pollutant or Parameter		Screening Methods	Semi-Quantitative Methods	Refined Methods
Criteria:	O_3	Passive Sampling, Dosimeter		UV Photometry
	SO_2	Colorimetric tubes, Diffusion Tubes		Pulsed Fluorescence; Flame Photometric Detection (FPD)
	NO_2	Diffusion Tubes		Gas Phase Chemiluminescence with O_3
	PM_{10}	Personal Dust Monitors	Personal Dust Monitors*, Saturation Sampling with Mid Volume Samplers	High Volume Sampling, TEOM®
	CO	Colorimetric Tubes, Diffusion Tubes	Saturation Sampling with Tedlar Bags	Nondispersive Infrared Method, Gas Filter Correlation, Photometry
	Pb	Not Applicable	Not Applicable	High Volume Sampling with Atomic Absorption Analysis
Deposition:	SO_4^{2-}	Not Applicable	Deposition Buckets	High Volume Sampling with Wet Chemistry
	NO_3^-	Not Applicable	Deposition Buckets	High Volume Sampling with Wet Chemistry
Organics:	PAH	NMHC to screen for PAH		EPA TO Method 13 (PUF)
	VOC	Dosimeters, Diffusion Tubes		EPA TO Method 14 (SUMMA® Canister Sampling)
	Aldehydes	Colormetric, or Diffusion Tubes for Formaldehydes		EPA TO Method 5 (Impinger with DNPH Reagent)
	CH_4	Organic Vapor Analyzer	Organic Vapor Analyzer*	Flame Ionization Detection
	NMHC	Photoionization Detector, Colorimetric Tubes	Photoionization Detector*	Flame Ionization Detection, EPA TO Method 12
	POM	Colorimetric Tubes		See PAH
Other:	TSP	Personal Dust Monitors		High Volume
	$PM_{2.5}$	Personal Dust Monitors	Saturation Sampling	Retrofitted High Volume Sampling, TEOM®
	Metals	Not Applicable	Not Applicable	High Volume Sampling with Atomic Absorption Analysis
	CO_2	Colorimetric Tubes, Diffusion Tubes		Gas Filter Correlation
	Visibility	Camera	Tape, $PM_{2.5}$ Regression Analysis	IMPROVE protocol, Nephelometer, Transmissometer
	Meteorology	Should be measured for all levels of monitoring		

* These instruments can be used for semi-quantitative applications if calibrated appropriately.
Ref: These are EPA-designated reference methods; other refined methods have been designated as "equivalent" by the EPA
TEOM®: Tapered Element Oscillating Microbalance PUF: polyurethane foam, SUMMA®: registered trademark of canisters, DNPH: 2,4-dinitrophenylhydrazine , IMPROVE: Interagency Monitoring of Protected Visual Environments

FIGURE 5-1

Key to Pollutants by Source Type

Chap. No.	Sources	Pollutant or Parameter: CRITERIA						ORGANICS								DEPOSITION		OTHER						
		SO_2	PM_{10}	CO	NO_2 (NO_X)	Lead	Ozone	Aldehydes	Hydrocarbons	Methane	Nonmethane hydrocarbons (NMHC)	Polycyclic organic matter (POM)	Volatile organic compounds (VOCs)	Polycyclic aromatic hydrocarbons (PAH)	Total organic compounds (TOCs)	SO_4^{2-}	NO_3^-	$PM_{2.5}$	TSP	CO_2	Metals	Visibility	Meteorology
3.1	**WOOD COMBUSTION**																						
3.1.1	Wildfire and prescribed natural fire		▲	▲	▲		▲	▲[1]					▲[1]	▲[1]	▲[1]		▲[1]	▲	▲	▲		▲[1]	Can be measured for all sources.
3.1.2	Prescribed burning		▲	▲	▲		▲	▲[1]					▲	▲[1]	▲[1]		▲[1]	▲	▲	▲		▲[1]	
3.1.3	Other open burning (wood residue)	▲	▲	▲					▲	▲	▲		▲			▲[1]		▲				▲[1]	
3.1.4	Residential fireplaces	▲	▲	▲	▲	▲[1]		▲				▲	▲		▲	▲[1]	▲[1]	▲		▲		▲[1]	
3.1.5	Residential wood stoves	▲	▲	▲	▲	▲[1]				▲	▲	▲		▲	▲	▲[1]	▲[1]	▲	▲	▲	▲	▲[1]	
3.2	**FUGITIVE DUST**																						
3.2.1	Vehicle traffic on unpaved roads		▲															▲	▲			▲[1]	
3.2.2	Vehicle traffic on paved roads		▲															▲	▲			▲[1]	
3.2.3	Heavy construction operations (fugitive dust)		▲															▲	▲			▲[1]	
3.2.4	Heavy-duty construction equipment (e.g., grading, hauling)		▲															▲	▲			▲[1]	
3.3	**INTERNAL COMBUSTION ENGINES** (exhaust)																						
3.3.1	Gasoline and diesel industrial engines (stationary)	▲	▲	▲	▲			▲	▲				▲	▲	▲					▲		▲[1]	
3.3.2	Motor vehicle emissions		▲	▲		▲[1]	▲											▲	▲			▲[1]	
3.3.3	Large diesel engines (stationary)	▲	▲	▲	▲				▲	▲	▲			▲	▲			▲	▲	▲	▲	▲[1]	
3.4	**ROAD BUILDING**																						
3.4.1	Asphalt paving												▲										
3.4.2	Asphaltic concrete plants	▲	▲	▲	▲							▲	▲		▲			▲	▲	▲	▲		
3.5	**ROAD MATERIALS PROCESSING**																						
3.5.1	Crushed stone processing		▲															▲	▲			▲[1]	
3.5.2	Sand and gravel processing		▲															▲	▲			▲[1]	
3.5.3	Ore crushing and grinding		▲															▲	▲			▲[1]	
3.6	**OIL AND GAS DEVELOPMENT**																						
3.6.1	Well field emissions	▲	▲	▲	▲	▲			▲	▲			▲					▲		▲			
3.6.2	Tank farm emissions	▲	▲	▲	▲				▲	▲			▲					▲					
3.7	**MISCELLANEOUS**																						
3.7.1	Wind erosion of bare or vegetated soil		▲												▲			▲	▲			▲[1]	

[1] Emissions not characterized in Chapter 3.

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Camera

Documenting visibility events and trends is an important aspect of evaluating existing or potential impairment in Class I and other visibility sensitive areas. Photography is an efficient way to document events and trends on a media that is a valuable analytical tool and is also easily interpreted by decision makers and the public. The automatic camera visibility monitoring station takes 35mm slides of a selected vista at user-selected times throughout the day.

Colorimetric Tubes

Colorimetric detector or indicator tubes allow the direct indication of airborne chemical levels. With this technique, a known volume of air is drawn through a tube containing a chemical reagent. The reagent changes color in the presence of the pollutant, and the length of the stain or color intensity indicates the airborne chemical levels. A scale is printed on each tube for interpretation of the reading. Generally, colorimetric tubes are useful for air pollution studies, although in most situations the currently available tubes do not have the required sensitivity and in some cases they are not compound specific. There are three types of color detector tubes available: (1) short-term tubes using a hand operated pump; (2) long-term tubes using a low flow pump; and (3) passive color badges or diffusion tubes which operate on the principle of diffusion.

Deposition Buckets

This method measures particulate fallout on a known surface. Particulate is collected in a bucket with liquid (usually water) over a particular period of time. The liquid is evaporated and particulate mass measured and reported in mass per unit area per time.

Dosimeter or Badge Method

Some gases and vapors can be sampled passively–without a pump–using gas monitoring badges. Badges are available with a variety of collection media including solid adsorbents, liquid medium, chemically impregnated tape, and reagent-filled tubes. In all cases, the air sample comes into contact with the badge by diffusion. Analysis techniques vary with the badge type and chemical sampled and include color change, gas chromatography, and other analytical methods.

Flame Ionization Detector

This technique is used to quantify hydrocarbons. After separation of chromatographic techniques, methane and other hydrocarbons are separately analyzed using a Flame Ionization Detector. The sample is burned in a hydrogen flame and the carbon-containing compounds form ions which are collected by a voltage across the flame. The ion current is electronically detected, amplified, and recorded.

Flame Photometric Detection (FPD)

Measurements are based on the intensity of spectral lines resulting from excitation of sulfur atoms in a hydrogen flame. Emissions from sulfur in the flame which are proportional to the amount of sulfur dioxide present, are measured and recorded.

Gas Filter Correlation

Gas filter correlation spectroscopy is based on comparison of the detailed structure of the infrared absorption spectrum of the measured gas to that of other gases also present in the sample being analyzed. The technique is implemented by using a high concentration sample of the measured gas; in this case, CO, as a filter for the infrared radiation transmitted through the analyzer, hence the term GFC.

Radiation from an infrared (IR) source is chopped and then passed through a rotating gas filter wheel containing a CO gas cell and an N_2 gas cell. The radiation going through the CO cell has the CO absorption wavelength subtracted out, or is "optically scrubbed." The radiation going through the N_2 cell is CO sensitive.

The two alternating beams of radiation emanating from the wheel reflect many times across a multi-pass optical absorption charger where the pollutant is monitored. If the air sample has no carbon monoxide, no attenuation of the infrared radiation on either side of the GFC wheel occurs, or, if any attenuation occurs (from gaseous species other than carbon monoxide), it will be equal on both sides with a net change of zero. If carbon monoxide is present in the air sample, then the beam generated by the CO side of the wheel will experience no further attenuation; however, the beam generated by the N_2 side of the wheel will be attenuated by CO present in the optical charger. This attenuation will create an "imbalance" in the signals going to the detector. This "imbalance" is directly proportional to the concentration of CO in the optical chamber.

Gas Phase Chemiluminescence with O_3

Chemiluminescent detection is used in the detection of oxides of nitrogen (NO_x). The air sample is continuously pumped into two paths within the analyzer, one leading through a converter to reduce nitrogen dioxide (NO_2); the other bypass the converter. Both samples reach reaction chambers where the nitric oxide is detected by its chemiluminescent (light emitting) reaction with ozone. The light emissions are detected by photomultiplier tubes, amplified, and recorded.

High-Volume Sampling (PM_{10} and TSP)

Samples are collected with high volume samplers which operate somewhat like a vacuum cleaner. Air is drawn through a pre-weighted fiber filter at about 40 cubic feet per minute for PM_{10} sampling and 50 cubic feet per minute for TSP sampling. After the sampling period, the filter is removed and reweighed. The difference between the starting weight and the

ending weight is the sample weight and is expressed as micrograms of fine particulate per cubic meter of air sampled.

High-Volume Sampling with Atomic Absorption (AA)

If light of the proper wavelength strikes a free, ground-state atom, the atom may absorb the light in a process known as atomic absorption (AA). By measuring the amount of light absorbed, a quantitative measurement of the analyte concentration can be made.

Atomic absorption has rapidly become the most widely used analytical technique for quantitative trace metal analysis. The technique is directly applicable to some 68 elements, including most of the metals and semi-metals, but excludes sulfur, carbon, halogens, and inert gases. Air samples are first collected on a glass fiber filter using high volume sampling techniques, and then sent to a laboratory where the sample is first extracted and then analyzed using AA. Advantages include specificity, speed, ease of use, and excellent sensitivity. Detection limits are typically in the sub-ppb to low ppm range by weight in the sample solution.

High-Volume Sampling with Wet Chemistry

The recommended method for strong acid in aerosols is collection on inert filter media, ultrasonic extraction into weak acid, and titration with base using a Gran plot to determine the equivalence point. For sampling periods longer than about 6 h (depending on ambient levels), a virtual impactor-based sampler collection particles on Teflon filter medium should be used. With shorter term sampling for which high-volume sampling apparatus is required, acid-treated quartz filters can be used, preferably with a cyclone preseparator for coarse particle removal. Automation of the titration procedure using coulometric generation of hydroxide is a practical necessity when large numbers of samples must be processed.

IMPROVE Protocol

A variety of monitoring techniques exist to document visibility conditions and to make quantitative measurements of the atmospheric properties that affect visibility. The IMPROVE Program (Interagency Monitoring of Protected Visual Environments) has partitioned visibility-related characteristics and measurements into three groups.

Optical: the ability of the atmosphere to scatter or absorb light passing through it. The physical properties of the atmosphere are described by extinction, scattering, and absorption coefficients, plus an angular dependence of the scattering, known as the scattering phase function. Optical characteristics integrate the effects of atmospheric aerosols and gasses. Commonly applied optical monitoring instruments include transmissometers and nephelometers.

Scene: the appearance of a scene viewed through the atmosphere. Scene characteristics include observer visual range, scene contrast, color, texture, clarify and other descriptive

terms. Scene characteristics change with illumination and atmospheric composition. Photographs are an effective way to document scene characteristics.

Aerosol: the physical properties of the ambient atmospheric aerosols (chemical composition, size, shape, concentration, temporal, and spatial distribution and other physical properties) through which a scene is viewed. Fine particle measurements are commonly made to quantify aerosol characteristics.

Nephelometer

The nephelometer measures a common property of small particles in the air: their ability to scatter light and cause visibility reduction. The instrument measures the scattering (Bscat) of the sample by drawing air into the detection chamber where it is illuminated by a pulsed-flash lamp. The scattered light is measured over a range of angles by means of a photomultiplier tube. This signal is averaged, amplified, and recorded. The amount of light scattered is usually proportional to the particle mass concentration of particles less than 2.5 micrometers in diameter and to observed visibility.

Nondispersive Infrared (NDIR)

Infrared energy from a source is passed through a cell containing the gas sample to be analyzed and simultaneously through a reference cell containing a non-absorbing gas. Carbon monoxide in the sample absorbs some of the energy, creating an out-of-balance condition in the detector. The imbalance is proportional to the amount of carbon monoxide in the sample air and is electronically amplified and recorded.

Organic Vapor Analyzers

An organic vapor analyzer (OVA) can detect and measure several organic gases and vapors using flame ionization or photoionization techniques. It can provide continuous readout for screening and surveying purposes as well as quantitative analyses when the chromatograph mode is selected. The sensitivity of these meters ranges from 0 to 2,000 parts per million (for a photoionization detector) and 0 to 50,000 ppm (for a flame ionization detector).

Passive Sampling (Diffusion)

Passive samplers operate on the colorimetric detection principle. Ambient air passively moves over chemically treated paper filters that are sensitive to the gas to be measured. This type of sampling is called passive because it requires no pumps or other powered systems to collect the air sample. The gas is collected through natural diffusion. After the sample is collected (from 1 day to 30), the filter is returned to a lab, and the change in the reflectance of the colorant is determined, and the concentration is reported in parts per billion (ppb) over the exposure period.

Personal Dust Monitors

Personal dust monitors are direct-reading, real-time monitors that can measure dust, aerosols, fumes, and mists. The output can be updated every 10 seconds. With special attachments, a personal dust monitor can measure respirable particulate. Concentrations can be measured over the range of 0.01 to 100 mg/m^3. These instruments are lightweight and battery operated, and are usually used to measure worker exposure at a site.

Photoionization Detector

These detectors measure current flow between two electrodes caused by ionization of the gas by ultraviolet radiation. These detectors are used in worker exposure applications and measure volatile organic compounds. These instruments can provide headspace detection of organics in soil, water, and other matrices.

Pulsed Fluorescence

This technology is used to measure sulfur dioxide. The air sample enters a chamber which is irradiated by an ultraviolet source, causing sulfur dioxide in the sample stream to fluoresce. The fluorescence which is proportional to the amount of sulfur dioxide present, is measured and recorded.

Saturation Sampling for Particulate Matter and Carbon Monoxide

In saturation sampling, a network of samplers is deployed in an area to determine where the worst air quality problems exist. In addition to providing data for environmental impact studies, saturation sampling is frequently used to determine the location for permanent monitoring sites, define boundaries of air quality concerns and extent of point source impacts.

Certain brands of saturation samplers can be equipped with Tedlar® bags for measurement of gas concentrations such as CO. After sampling, the Tedlar® bag is returned to a lab for analysis. Bags, used with a sampling pump, can be used for diluting and detecting gas concentrations that exceed the measurement capabilities of common analytical instruments. Bag sampling is not recommended for unstable or highly reactive compounds.

TEOM®

The Tapered Element Oscillary Microbalance (TEOM®) is a real time particulate monitoring that can measure particulate matter 10 µm in aerodynamic diameter or less and 2.5 µm. It has been approved by the U.S.E.P.A. as an equivalent method. Air is passed through a filter, on which particulate is deposited, and the filtered air then passes through a tapered tube to a flow controller. The tapered tube with the filter on its end is maintained in oscillation. The frequency of oscillation is dependent upon the physical characteristics of the tapered tube and the mass. As particulate land on the filter, the filter mass change is detected as a frequency

change in the oscillation of the tube. When this mass change is combined with the flow rate through the system, the instrument yields a measurement of the particulate in real time.

TO Method 5 (Impinger with DNPH Reagent)

This method describes the determination of individual aldehydes and ketones in ambient air. Ambient air is drawn through a midget impinger containing 10 ML of a DNPH reagent and 10 ML of isooctane. The DNPH derivatives are determined using reversed phase HPLC with an ultraviolet (UV) adsorption detector.

TO Method 12

This method is used to determine non-methane hydrocarbons (NMHC) in ambient air. An air sample is collected directly and analyzed onsite by a GC system or collected into a precleaned sample canister and analyzed offsite using cryogenic preconcentration and direct flame ionization. The concentrations of NMOC are reported in units of parts per million carbon (ppmC).

TO Method 13 (PUF)

This method describes a sampling and analysis procedure for polynuclear aromatic hydrocarbons (PAHs) and polycyclic organic matter (POM). Ambient air is drawn through a quartz filter and adsorbent cartridge using a sampler similar to a high volume particulate sampler. The filter and cartridge are then analyzed by gas chromatography (GC) with flame ionization (FI) and mass spectrometry (MS) detection (GC/FI) and GC/MS) or high performance liquid chromatography (HPLC).

TO Method 14 (Summa® Canister Sampling)

This method describes the determination of VOCs in ambient air using Summa® passivated canister sampling and gas chromatographic analysis. The method is based on collection of whole air samples (usually 6 liters) using an initially evacuated canister and pump-ventilated sample line during sample collection. The VOCs are subsequently separated by gas chromatography and measured by multidetector techniques.

Transmissometer

A transmissometer, used in visibility monitoring, measures the ability of the atmosphere to transmit light. This instrument measures the total extinction coefficient (scattering plus absorption).

UV Photometry

This technology is used to measure ozone. This method is based on the photometric assay of ozone concentrations in a dynamic flow system. The concentration of O_3 is determined in an absorption cell from the measurement of the amount of light absorbed at a wavelength of

254 nm. The method is based on the absorption coefficient of FO_3 at 254 nm, the optical path length.

Monitoring Plans

A monitoring plan prepared by the Forest Service should be submitted to and approved by the permit-granting authority before any PSD-level monitoring begins. Note that approval of the monitoring plan before a monitoring program is started is not a requirement. However, because the network size and station locations are determined on a case-by-case basis, it would be prudent for the owner or operator to seek review of the network and the overall monitoring plan from the permit-granting authority before collecting data. This review could avoid delays in the processing of the permit application and could also result in the elimination of unnecessary monitoring. Delays may result from insufficient, inadequate, poor, or unknown quality data. Table 5-2 lists the types of information that should be included in the monitoring plan.

Table 5-2 Minimum Contents of Monitoring Plan	
I.	**Source Environment Description (within 2 kilometers of source)** • Topographical description • Land-use description • Topographical map of the source and the environs (including the location of existing stationary sources, roadways, and monitoring sites) • Climatological description • Quarterly wind roses (from meteorological data collected at the source or other representative meteorological data)
II.	**Sampling Program Description** • Time period for which the pollutant(s) will be measures • Rationale for location of the monitors (including modeling results and an analysis of the existing sources in the area) • Rationale for joint utilization of the monitoring network by other PSD sources
III.	**Monitor Site Description** • Universal transverse Mercator (UTM) coordinates • Height of the sampler (air intake) above the ground • Distance from obstructions and heights of obstructions • Distance from other sources (stationary and mobile) • Photographs of each site (five photographs-one in each cardinal direction looking from each existing sampler or where a future sampler will be located, and one closeup of each existing sampler or where a future sampler will be located; ground cover should be included in the closeup photograph)
IV.	**Monitor Description** • Name of manufacturer • Description of calibration system to be used • Type of flow control and flow recorder
V.	**Data Reporting** • Format of data submission • Frequency of data reporting
VI.	**Quality Assurance Program** • Calibration frequency • Independent audit program • Internal quality control procedures • Data precision and accuracy calculation procedures

Quality Assurance

Quality assurance (QA) consists of two distinct yet equally important functions. One function is to assess the quality of the monitoring data by determining its precision and accuracy. Precision is a measure of the repeatability of data results obtained during a given monitoring period. Accuracy is a measure of the closeness of an observed measurement to the true value.

The second function of quality assurance is to control and improve the quality of the data by implementing a quality control policy or plan, procedures, and corrective action. The assessment function and the control effort work together to produce quality data that are acceptable. A project quality assurance plan (EPA, 1975) should include the following at a minimum:

- Project description
- Project organization
- QA objectives for measurement data in terms of precision, accuracy, completeness, representativeness, and comparability
- Sampling procedures and frequency
- Calibration procedures and frequency
- Analytical procedures
- Data reduction, validation, and reporting
- Internal quality control checks and frequency
- Performance and system audits and frequency
- Preventive maintenance
- Specific routine procedures to be used to assess data precision, accuracy, and completeness of specific measurement parameters involved
- Corrective action
- Quality assurance reports to management

Chapter 6
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Acronyms and Abbreviations

ADT	average daily traffic
AIRS	Aeromatic Information Retrieval System
AQCR	air quality control region
ASA	air stagnation advisory
BACM	best available control measures
BACT	best available control technology
BaP	benzo(a)pyrene
BBS	bulletin board system
BLP	Buoyant Line and Point Source Dispersion Model
CAA	Clean Air Act
CALINE3	California Line Source Dispersion Model
CBM-II	Carbon Bond Mechanism
CEQ	Council on Environmental Quality
CFR	Code of Federal Regulations
CHIEF	Clearinghouse for Inventories and Emission Factors
CI	compression ignition
CO	carbon monoxide
CO_2	carbon dioxide
CTDMPLUS	Complex Terrain Dispersion Model Plus Algorithms for Unstable Situations
CTSCREEN	CTDMPLUS Screening Mode
°C	degrees Celsius
°F	degrees Fahrenheit
DOS	Disk Operating System
EA	environmental assessment
EGA	enhanced graphics adapter
EGR	exhaust gas recirculation
EIS	environmental impact statement
EPA	U.S. Environmental Protection Agency
EPM	Emissions Production Model
FIRE	Factor Information Retrieval
FONSI	finding of no significant impact
g	gram
g/VMT	grams per vehicle mile traveled
g/m^2	grams per square meter
g/mi	grams per mile
g/VKT	grams per vehicle kilometer traveled
HAPs	hazardous air pollutants
HMA	hot mix asphalt
HNO_3	nitric acid
hp	horsepower
IC	internal combustion
in	inch
ISC2	Industrial Source Complex Model

IWAQM	Interagency Workgroup on Air Quality Modeling
KB	kilobytes
kg	kilogram
kg/km	kilograms per kilometer
km/hr	kilometers per hour
kW	kilowatt
lb	pound
lb/mi	pounds per mile
lb/VMT	pounds per vehicle mile traveled
m/s	meters per second
MB	megabytes
MC	medium cure
MESOPUFF II	Mesoscale Puff Model
Mg	megagram
mg/m^3	milligrams per cubic meter
$\mu g/m^3$	micrograms per cubic meter
µm	micrometer
mm	millimeters
mph	miles per hour
MS	Microsoft
NAAQS	national ambient air quality standard
NAPAP	National Acid Precipitation Assessment Program
NEPA	National Environmental Policy Act
NO_2	nitrogen dioxide
NO_3	nitrate
NOAA	National Oceanic and Atmospheric Administration
NO_x	nitrogen oxides
NSPS	new source performance standards
NTIS	National Technical Information Service
O_3	ozone
OMS	Office of Mobile Sources
OVA	organic vapor analyzer
QA	quality assurance
PAHs	polycyclic aromatic hydrocarbons
PAL-DS	Point, Area, Line Source Algorithm
Pb	lead
PC	personal computer
PLUVUE II	Plume Visibility Model
PM	particulate matter
PM_{10}	inhalable particulate matter; particulate matter with an aerodynamic diameter of 10 micrometers or less
$PM_{2.5}$	particulate matter less than 2.5 micrometers in diameter
POM	polycyclic organic matter
ppb	parts per billion
ppm	parts per million
PSD	prevention of significant deterioration

RACM	reasonably available control measures
RADM	Random-Walk Advection and Dispersion Model
RAM	random-access memory
RAP	reclaimed asphalt pavement
RC	rapid cure
RPM-II	Reactive Plume Model
RTECS	Registry of Toxic Effects of Chemical Substances
s/L	silt loading
SASEM	Simple Approach Smoke Estimation Model
SC	slow cure
SCC	Source Classification Code
SCR	selective catalytic reduction
SCRAM	Support Center for Regulatory Air Models
SI	spark ignition
SIP	state implementation plan
SO_2	sulfur dioxide
SO_4	sulfate
SO_x	sulfur oxides
SP	suspended particulate
SPECIATE	VOC/PM Speciation Data System
TNMOC	total nonmethane organic compounds
TOCs	total organic compounds
TSARS	Tiered Smoke Air Resources System
TSP	total suspended particulate matter
TTN	Technology Transfer Network
UAM	Urban Airshed Model
USGS	U.S. Geological Survey
UTM	universal transverse Mercator
VDT	vehicle distance traveled
VGA	video graphics array
VISCREEN	Visual Impact Screening Model
VKT	vehicle kilometer traveled
VMT	vehicle mile traveled
VOC	volatile organic compound

Glossary

Air contaminant. A dust, fume, gas mist, odor, smoke, vapor, soot, pollen, carbon, acid or particulate matter or any combination thereof.

Air monitoring. See monitoring.

Air pollutant. Any substance in air that could, if in high enough concentration, harm humans, other animals, vegetation, or material. Pollutants may include almost any natural or artificial composition of matter capable of being airborne. They may be in the form of solid particles, liquid droplets, gases, or a combination of these. Generally, they fall into two groups: those emitted directly from identifiable sources and those produced in the air by interaction between two or more primary pollutants or by reaction with normal atmospheric constituents–with or without photoactivation. Exclusive of pollen, fog, and dust, which are of natural origin, about 100 contaminants have been identified and fall into the following categories: solids, sulfur compounds, volatile organic chemicals, nitrogen compounds, oxygen compounds, halogen compounds, radioactive compounds, and odors.

Air pollution alert. A statement issued by an Air Quality Regulatory Agency due to high measured concentrations of pollutants. The alert remains in effect until monitoring shows a decrease in pollutant levels. Should conditions worsen, air pollution warnings and emergencies may be issued. At each stage (alert, warning and emergency) additional emission restrictions are put into effect so as to not exacerbate the situation. Essentially, at the emergency level all industrial activities and auto usage stops. See Air Stagnation Advisory.

Air pollution potential. The relative ability of the atmosphere to dilute and transport pollutants. A high potential per unit of pollution results from low dilution rates and little transport by the wind. See atmospheric Stability.

Air quality. The composition of air with respect to quantities of pollution therein; used most frequently in connection with "standards" of maximum acceptable pollutant concentrations. Used instead of "air pollution" when referring to programs.

Air Quality Maintenance Area (AQMA). An area that has been identified by an Air Quality Regulatory Agency to have the potential for exceeding any federal or state ambient air quality standard due to projected growth and development. See Nonattainment Area.

Air quality model. Mathematical or quantitative representation or simulation of air quality processes; e.g., emission models, receptor models, or air quality dispersion models. See Model.

Air quality standards. The level of pollutants prescribed by regulations that may not be exceeded during a specified time in a defined area.

Air stagnation advisory (ASA). A statement issued by a National Weather Service Forecast Office when atmospheric conditions are stable enough such that the potential exists for air pollutants to accumulate in a given area. The statement is initially issued when conditions are expected to last for at least 36 hours. See Air Pollution Alert.

Air toxics. See hazardous air pollutants.

Airborne particulate matter. Total suspended particulate matter found in the atmosphere as solid particles or liquid droplets. Chemical composition of particulates varies widely, depending on location and time of year. Airborne particulates include: windblown dust, emissions from industrial processes, smoke from the burning of wood and coal, and the exhaust of motor vehicles.

Alternative fuels. Fuels such as methanol, ethanol, natural gas, and liquid propane gas that are cleaner burning and help to meet some state's mobile and stationary emission standards.

Ambient air. Any unconfined portion of the atmosphere: open air and surrounding air. The air occurring at a particular time and place outside of structures. Often used interchangeably with outdoor air.

APCD (Air Pollution control District). A county agency with authority to regulate stationary, indirect, and area sources of air pollution (e.g., power plants, highway construction, and housing developments) within a given county, and governed by a district air pollution control board composed of the elected county supervisors. (Compare AQMD).

AQMD (Air Quality Management District). A group of counties or portion of counties, or an individual county specified in law with authority to regulate stationary, indirect, and area sources of air pollution within the region and governed by a regional air pollution control board comprised mostly of elected officials from within the region. (Compare APCD).

Area source. An air pollution source that is neither a major stationary source nor a mobile source. Area sources include broadcast burning and vehicles traveling on a parking lot.

Area source. A source category of air pollution that generally extends over a large area. Prescribed burning, field burning, home heating, and open burning are examples of area sources. See Point Source, Source

Atmospheric stability. The degree to which vertical motion in the atmosphere is enhanced or suppressed. Vertical motions and pollution dispersion are enhanced in an unstable atmosphere. Stability suppresses vertical motion and limits pollution dispersion. See Also Air Pollution Potential, Inversion, Stable Layer of Air.

Attainment area. A geographic area which is in compliance with the National and/or California Ambient Air Quality Standards (NAAQS or CAAQS). An area considered to have air quality as good as or better than the national ambient air quality standards as defined in

the Clean Air Act. An area may be an attainment area for one pollutant and a nonattainment area for others.

Available fuel. The portion of the total combustible material that fire will consume under given conditions. This could be duff, woody, herbaceous or litter.

Background (concentration, level). In air pollution control, the concentration of air pollutants in a definite area during a fixed period of time prior to the starting up, or the stoppage, of a source of emission under control In toxic substances monitoring, the average presence in the environment, originally referring to naturally-occurring phenomena.

BACM (Best Available Control Measures). Control measures to be developed by EPA which apply to residential wood combustion, fugitive dust, and prescribed and silvicultural burning in "serious" PM-10 non-attainment areas. BACM is more stringent than RACM. Final guidance on BACM is still being developed.

BACT (Best Available Control Technology). The most up-to-date methods systems, techniques, and production processes available to achieve the greatest feasible emission reductions for given regulated air pollutants and processes. BACT is a requirement of NSR (New Source Review) and PSD (Prevention of Significant Deterioration).

Burn day. A day officially determined by meteorologists and air pollution specialists to have favorable weather conditions for good dispersal of smoke from the burning of agricultural and wildlands refuse.Carbon dioxide (CO_2). A colorless, odorless, nonpoisonous gas that results from fossil fuel combustion and is normally a part of the ambient air.

Carbon monoxide (CO). A colorless, odorless, poisonous gas produced by incomplete fossil fuel combustion; primarily emitted by mobile sources. Over 80% of the CO emitted in urban areas is contributed motor vehicles. CO interferes with the blood's ability to carry oxygen to the body's tissues and results in numerous adverse health effects. CO is a criteria air pollutant.

Carbon dioxide (CO_2). A colorless, odorless, gas that occurs naturally in the earth's atmosphere. Significant quantities are also emitted into the air by fossil fuel combustion. Emissions of CO_2 have been implicated with increasing the greenhouse effect.

Carcinogen. Any substance that can cause or contribute to the production of cancer.

Class I areas. Under the 1977 Clean Air Act amendments (42 U.S.C. 7401 et seq), all international parks, national parks greater than 6000 acres and national wilderness areas greater than 5000 acres which existed on August 7, 1977. This class provides that most protection to pristine lands by severely limiting the amount of additional air pollution which can be added to these areas.

Clean Air Act (CAA). A federal law enacted to insure that air quality standards are attained and maintained. Initially passed by Congress in 1963, it has been amended several times, the latest being August of 1977.

Criteria pollutants. Those air pollutants designated by EPA as potentially harmful and for which ambient air standards have been set to protect the public health and welfare. The criteria pollutants are carbon monoxide, sulfur dioxide, particulate matter, nitrogen dioxide, ozone, hydrocarbons, and lead. The 1970 amendments to the Clean Air Act required EPA to set National Ambient Air Quality Standards (NAAQS) for certain pollutants known to be hazardous to human health. EPA has identified and set standards to protect human health and welfare for six pollutants: ozone, carbon monoxide, total suspended particulates, sulfur dioxide, lead, and nitrogen oxide. The term "criteria pollutants" derives from the requirement that EPA must described the characteristics and potential health and welfare effects of these pollutants. It is on the basis of these criteria that standards are set or revised.

Dispersion. In air pollution terminology, loosely applied to the removal (by whatever means) of pollutants from the atmosphere over a given area; or the distribution of a given quantity of pollutant throughout a volume of atmosphere.

Dispersion modeling. Representing the scattering of contaminants through the atmosphere with regard to time and space.

Drift smoke. Smoke in evidence after all fire in the fuel has been extinguished. Generally considered to be the smoke lingering in an area or the smoke transported downwind which cannot be traced back to the burn site by tracking the main plume. See Residual Smoke, Plume.

Emission. Pollution discharged into the atmosphere from smokestacks, other vents, and surface areas of commercial or industrial facilities; from residential chimneys; and from motor vehicle, locomotive, or aircraft exhausts. A release into the outdoor atmosphere of air contaminants.

Emission factor. The relationship between the amount of pollution produced and the amount of raw material processed. The mass of particulate matter produced per unit mass of fuel consumed (pounds per tone, grams per kilogram). For example, an emission factor for crushing stone would be the number of pounds of particulates per ton of raw materials.

Emission inventory. An estimate of the amount of pollutants emitted from mobile and stationary sources into the atmosphere over a specific period such as a day or a year.

Emission offset (also known as an emission-trade-off). A rule-making concept whereby approval of a new or modified stationary source of air pollution is conditional on the reduction of emissions from other existing stationary sources of air pollution. These reductions are required in addition to reductions required by BACT.

Emission standard. The maximum amount of pollutant that is allowed to be discharged from a polluting source such as an automobile or smoke stack.

Emission rate. The amount of smoke produced per unit of time (lb./min). Emission Rate = Available Fuel x Burning Rate x Emission Factor.

Emission standard. Limitation on the release of a contaminant, or multiple contaminants, to the ambient air from a single source.

Episode (pollution). A condition of poor contaminant dispersion which may result in concentrations considered potentially harmful to health or welfare. Episodes may also occur during periods of fairly good dispersion if the source of air contaminants is extremely large.

Environmental impact statement (EIS). A document required of federal agencies by the National Environmental Policy Act for major projects or legislative proposals that significantly affect the environment. A tool for decisionmaking, it describes the positive and negative effects of the undertaking and lists alternative actions.

EPA (Environmental Protection Agency). The United States agency charged with setting policy and guidelines, and carrying out legal mandates for the protection of national interests in environmental resources.

Equilibrium moisture content. The value that the actual fuel moisture will approach if the fuel is exposed to constant atmospheric conditions of temperature and humidity for an infinite length of time (forever).

FCAA (Federal Clean Air Act): A federal law passed in 1970 and amended in 1977 and 1990 which forms the basis for the national air pollution control program. Basic elements of the act include national ambient air quality standards for major air pollutants, air toxics standards, acid rain control measures, and enforcement provisions.

Fine particulate matter. "Fine" particulates are those particles less than 10-15 microns in size. Fine particles have longer residence time in the atmosphere, are more harmful to health and have greater impact on visibility than larger particles. "Inhalable (respirable) particulate" matter is those particles less that 2.5 microns in size. Respirable particulates have an especially long residence time in the atmosphere and penetrate deeply into lungs. particles from smoke are primarily in the respirable size range. Aerosol is often used interchangeably for the smaller airborne particulate matter. However, aerosols are more precisely defined as particles in a gaseous medium. See Particulate Matter, PM-10

Fuel loading. The amount of fuel present expressed quantitatively in terms of weight of fuel per unit area. This may be available fuel or (consumable fuel) total tuel and is usually dry weight.

Fuel type. An identifiable association of fuel elements of distinctive species, form, size, arrangement, or other characteristics, that will cause a predictable rate of fire spread or difficulty of control, under specified weather conditions.

Fugitive dust. Dust particles which are introduced into the air through certain activities such as soil cultivation, off-road vehicles, or any vehicles operating on open fields or dir roadways.

Fugitive emissions. Emissions not caught by a capture system.

Gaussian. Having a normal distribution; a bell-shaped curve.

Generator. A facility or mobile source that emits pollutants into the air or releases hazardous waste into water or soil.

Greenhouse effect. The warming of the earth's atmosphere caused by a build-up of carbon dioxide or other trace gases; it is believed by many scientists that this build-up allows light from the sun's rays to heat the Earth, but prevents a counterbalancing loss of heat.

Hazardous air pollutants (HAPs). Those listed in the Clean Air Act Amendments of 1990, as well as any added by EPA, that may present a threat of adverse health or environmental effects. Air pollutants which are not covered by ambient air quality standards but which, as defined in the Clean Air Act, may reasonably be expected to cause or contribute irreversible illness or death. Such pollutants include asbestos, beryllium, mercury, benzene, coke oven emissions, radionclides, and vinyl chloride.

Hydrocarbons. A general term for organic compounds that contain only carbon and hydrogen in the molecule. In photochemical pollution, they react with atomic oxygen and ozone to form new reactive compounds. Any of a large number of compounds containing various combinations of hydrogen and carbon atoms. They may be emitted into the air as a result of fossil fuel combustion, fuel volatilization, and solvent use, and are a major contributor to smog. (Also see ROG).

Inversion. An increase of temperature with height in the atmosphere. Vertical motion in the atmosphere is inhibited allowing for pollution buildup. A "normal" atmosphere has temperature decreasing with height. A layer of warm air in the atmosphere that lies over a layer of cooler air, trapping pollutants.

Major stationary sources. Term used to determine the applicability of Prevention of Significant Deterioration ("PSD") and new source regulations. In a non-attainment area, any stationary pollutant source that has a potential to emit more that 100 tons per year is considered a major stationary source. In PSD areas, the cutoff level may be either 100 or 250 tons, depending upon the type of source.

Micron. One millionth of a meter, a micrometer.

Mixing. A random exchange of air parcels on any scale from the molecular to the largest eddy.

Mixing height. Measured from the surface upward, the height to which relatively vigorous mixing due to convection occurs. Same as mixing depth. Use of the term normally implies presence of an inversion and the base of the inversion is the top of the mixed layer and defines the mixing height.

Mixed or mixing layer. That portion of the atmosphere from the surface up to the mixing height. This is the layer of air usually a sub-inversion layer, within which pollutants are mixed by turbulence and diffusion.

Model. A quantitative and mathematical representation or simulation which attempts to describe the characteristics or relationships of physical events. See Air Quality Model.

Monitoring. Periodic or continuous surveillance or testing to determine the level of compliance with statutory requirements and/or pollutant levels in various media or in humans, animals, and other living things.

National Ambient Air Quality Standards (NAAQSs). Standards set by the federal EPA for the maximum levels of air pollutants which can exist in the outdoor air without unacceptable effects on human health or the public welfare.

Nitrogen dioxide (NO_2). Product of combustion from transportation and stationary sources and a major contributor to acid deposition and the formation of ground level ozone in the troposphere.

Nitrogen oxides (NO_x). A pollutant that reacts photochemically in atmosphere with VOCs to form ozone; also contributes to acid rain and PM_{10}. A product of combustion from transportation and stationary sources an a major contributor to the formation of ozone in the troposphere and acid deposition.

Non-point source. An area identified by an Air Quality Regulatory Agency through ambient air monitoring (and designated by the Environmental Protection Agency), that presently exceeds Federal ambient air standards. See Air Quality Maintenance Area. Pollution sources that are diffuse and do not have a single point of origin or are not introduced into a receiving stream from a specific outlet.

NSR (New Source Review): A program used in development of permits for new or modified industrial facilities which are in a non-attainment area, and which emit non-attainment criteria air pollutants. The two major requirements of NSR are Best Available Control Technology and Emission Offset.

Nonattainment area. A geographic area that does not meet one or more of the national ambient air quality standards for the criteria pollutants designated in the Clean Air Act.

Nitrogen oxides (NO_x). A general term pertaining to compounds of nitric oxide NO), nitrogen dioxide (NO_2), and other oxides of nitrogen. Nitrogen oxides are typically created during combustion processes, and are major contributors to smog formation and acid deposition. NO_2 is a criteria air pollutant, and may result in numerous adverse health effects.

Ozone (O_3). A strong smelling, pale blue, reactive toxic chemical gas consisting of three oxygen atoms. A pollutant formed in the atmosphere, commonly referred to as smog, for which NAAQSs have been established; in the stratosphere, acts as protective filter for ultraviolet rays. Ozone is found in two layers of the atmosphere: the stratosphere and the troposphere. In the stratosphere, ozone is a form of oxygen found naturally that provides a protective layer that shields the earth from ultraviolet radiation's harmful health effects on humans and the environment. In the troposphere, ozone is a chemical oxidant and major component of photochemical smog. Ozone can seriously affect the human respiratory system and is one of the most prevalent criteria pollutants for which the Clean Air Act required EPA to set standards. Ozone in the troposphere is produced through complex chemical reactions of nitrogen oxides, which are among the primary pollutants emitted by combustion sources; hydrocarbons, which are released into the atmosphere through the combustion, handling, and processing of petroleum products; and sunlight.

Ozone precursors. Chemicals such as hydrocarbons and oxides of nitrogen, occurring either naturally or as a result of human activities, which contribute to the formation of ozone, a major component of smog.

Particulate matter (PM_{10} or TSP). Particulate matter is any liquid or solid particles. Fine particulates (PM_{10}) are those particles that have an aerodynamic diameter of 10 micrometers or less and for which a health-based NAAQS has been established. These particles have longer residence time in the atmosphere, are more harmful to health, and have greater impact on visibility than larger particles. Total suspended particulates (TSP) are particles that are 0.1 to 100 micrometers in length for which NAAQSs have been set to protect the environment. Fine liquid or solid particles such as dust, smoke, mist, fumes, or smog found in air or emissions.

Particulate mass concentration. The amount of particulate matter per unit volume of air usually expressed as micrograms per cubic meter (ug/m3).

Permit: Written authorization from a government agency (e.g., an air quality management district) that allows for the construction and/or operation of an emissions generating facility or its equipment within certain specified limits.

Plume. The segment of the atmosphere occupied by the emissions from a single source or a grouping of sources close together. A convection column, if one exists, forms a specific part of the plume.

Plume rise. How high above the level of release an emission plume rises.

PM_{10}. Particulate matter that measures 10 micrometers in diameter or less--a size considered small enough to invade the alveolar regions of the lung. PM_{10} is one of the six pollutants for which there is a national ambient air quality standard. See also particulate matter.

Point source. A stationary location or fixed facility from which pollutants are discharged or emitted. Also, any single identifiable source of pollution (for example, a pipe, ditch, ship, ore pit, or factory smokestack).

Prescribed burning. Controlled application of fire to wildland furles in either their natural or modified state, under such conditions as weather, fuel moisture, soil moisture, etc., as allows the fire to be confined to a predetermined area and at the same time to produce the intensity of heat and rate of spread required by further certain planned objectives of silviculture, wildlife habitat management, grazing, fire hazard reduction etc.

Prevention of Significant Deterioration (PSD). A program established under Part C of Title I to preserve air quality in areas already meeting NAAQSs. A program used in development of permits for new or modified industrial facilities in an area that is already in attainment. The intent is to prevent an attainment area from becoming a non-attainment area. This program, like NSR, can require BACT and, if an MQS is projected to be exceeded, Emission Offsets.

Reasonably Available Control Measures (RACM). Control measures developed by EPA which apply to residential wood combustion, fugitive dust, and prescribed and silvialltural burning in and around "moderate" PM-10 non-attainment areas. RACM is designed to bring an area back into attainment and uses a smoke management program which relies on weather forecasts for burn/no-burn days.

Reasonably Available Control Technology (RACT). The lowest emissions limit that a particular source is capable of meeting by the application of control technology that is both reasonable available, as well as technologically and economically feasible. RACT is usually applied to existing sources in non-attainment areas and, in most cases, is less stringent that new source performance standards.

Regional haze. A haze over large area with no attributable source.

ROG (reactive organic gas). A reactive chemical gas, composed of hydrocarbons, that may contribute to the formation of smog. Also sometimes refereed to as Non-Methane Organic Compounds (NMOCs).

SIP (State Implementation Plan). A document prepared by each state describing existing air quality conditions and measures which will be taken to attain and maintain national ambient air quality standards (see AQMP). EPA-approved state plans for the establishment, regulation, and enforcement of air pollution standards; plans that states must develop pursuant to § 110 and Part D of Title I to provide for attainment and maintenance of NAAQSs.

Smog. A combination of smoke, ozone, hydrocarbons, nitrogen oxides, and other chemically reactive compounds which, under certain conditions of weather and sunlight, may result in a murky brown haze that causes adverse health effects. The primary source of smog in urban areas is motor vehicles.

Smoke. A form of air pollution consisting primarily of particulate matter (i.e., particles). Other components of smoke include gaseous air pollutants such as hydrocarbons, oxides of nitrogen, and carbon pollutants such as hydrocarbons, oxides of nitrogen, and carbon monoxide. Sources of smoke may include fossil fuel combustion, agricultural and forest burning, and other combustion processes.

Smoke intrusion. Smoke from prescribed fire entering a designated area at unacceptable levels.

Smoldering phase. The overall reaction rate of the fire has diminished to a point at which concentrations of combustible gases above the fuel are too low to support a persistent flame envelope. Consequently, the temperature drops and gases condense. The smoke evolved during this phase is virtually soot-free, consisting mostly of tar droplets less that a micrometer in size.

Soot. Carbon dust formed by incomplete combustion.

Sounding. (Upper Air Sounding, Readiosonde) A sampling of upper air conditions made by means of instruments and a small radio transmitter on a free balloon. Automatic radio signals originated by action of weather instruments are sent to a ground receiver. These signals are interpreted for use in analyzing and predicting upper air conditions over a wide area of the earth. Weather elements determined at a number of altitude points as the balloon rises are temperature, atmospheric moisture, pressure, wind direction and speed. Similar soundings may be made using fixed balloons or tethersondes.

Source. A point, line, or area, at which mas or energy is added to a system, either instantaneously or continuously. Examples of sources in the context of air pollution are as follows: a smoke stack is a point source; a freeway is a line source; field or slash burning are area sources.

Stable Air. A mass of air that is not moving normally, so that it holds, rather than disperses pollutants.

Standard visual range (SRV). The visual range at which a black object can just be seen against the horizon. SRV is commonly used as an indicator of visibility.

Stationary sources. Non-mobile sources such as powerplants, refineries, and manufacturing facilities which emit air pollutants. (Contract with mobile sources).

Sulfur dioxide (SO_2). A pollutant emitted by sources using sulfur-bearing fuels that is a principal target of the acid rain control program; a heavy, pungent, colorless, gaseous air pollutant formed primarily by the combustion of fossil plants.

Surface low. An area on the earth's surface where atmospheric pressure is at a relative minimum. Winds at weather stations blow counter-clockwise around lows in the Northern Hemisphere but, due to friction with the earth's surface, tend to cross constant pressure lines toward the low center. Upon converging at the low center, air currents are forced to rise. As air rises it cools due to expansion. Cooling reduces its capacity to hold moisture; so cloudiness and precipitation are common in lows. A low center intensifies sufficiently it will take on the characteristics of a storm center with precipitation and strong winds.

Thermal trough. See Heat Trough and Heat Low.

Total suspended particulate matter (TSP). Particles emitted from a pollution source regardless of size. Federal and State ambient and emission standards exist for TSP (PM-10, PM-2.5 are small sized). See Particulate Matter, PM-10, Fine Particulate Matter.

Toxic. Relating to a harmful effect by a poisonous substance on the human body by physical contact, ingestion, or inhalation.

Toxic substance. A chemical or mixture that may present an unreasonable risk of injury to health or the environment.

Transport wind speed. A measure of the average rate of the horizontal transport of air within the Mixing Layer. May also be the wind speed at the final height of plume rise. Generally refers to the rate at which emissions will be transported from one area to another. See Mixing Layer.

Turbulence. A complex spectrum of fluctuating, disordered motion superimposed on the mean flow of liquid or gas.

User's Network for Applied Modeling of Air Pollution (UNAMAP). EPA supplied program tape of dispersion models used for prevention of significant deterioration (PSD) and permitting of new pollution sources.

Visibility. The distance that atmospheric conditions allow a person to see at a given time and location. Visibility reduction from air pollution is often due to the presence of sulfur and nitrogen oxides, as well as particulate matter.

Volatile organic compounds (VOCs). Hydrocarbon pollutants that react photochemically in sunlight with NO_x to produce ozone; any organic compound that participates in atmospheric photochemical reactions except for those designated by EPA as having negligible photochemical reactivity. Hydrocarbon compounds which exist in the ambient air. VOCs contribute to the formation of smog and/or may themselves be toxic. VOCs often have an odor, and some examples include gasoline, alcohol, and the solvents used in paint.

Appendix A
Government Agencies Directory

OUTDATED

Appendix B
189 Hazardous Air Pollutants

Appendix B

Hazardous Air Pollutants (Air Toxics)	
CAS Number	**Chemical Name**
75070	Acetaldehyde
60355	Acetamide
75058	Acetonitrile
98862	Acetophenone
53963	2-Acetylaminofluorene
107028	Acrolein
79061	Acrylamide
79107	Acrylic acid
107131	Acrylonitrile
107051	Allyl chloride
92671	4-Aminobiphenyl
62533	Aniline
90040	o-Anisidine
1332214	Asbestos
71432	Benzene (including benzene from gasoline)
92875	Benzidine
98077	Benzotrichloride
100447	Benzyl chloride
92524	Biphenyl
117817	Bis(2-ethylhexyl)phthalate (DEHP)
542881	Bis(chloromethyl)ether
75252	Bromoform
106990	1,3 Butadiene
156627	Calcium cyanamide
105602	Caprolactam
133062	Captan
63252	Carbaryl
75150	Carbon disulfide
56235	Carbon tetrachloride
463581	Carbonyl sulfide
120809	Catechol
133904	Chloramben
57749	Chlordane

Hazardous Air Pollutants (Air Toxics)	
CAS Number	**Chemical Name**
51285	2,4-Dinitrophenol
121142	2,4-Dinitrotoluene
123911	1,4-Dioxane (1,4-Diethyleneoxide)
122667	1,2-Diphenylhydrazine
106898	Epichlorohydrin (l-Chloro-2,3-epoxypropane)
106887	1,2-Epoxybutane
140885	Ethyl acrylate
100414	Ethyl benzene
51796	Ethyl carbamate (Urethane)
75003	Ethyl chloride (Chloroethane)
106934	Ethylene dibromide (Dibromoethane)
107062	Ethylene dichloride (1,2-Dichloroethane)
107211	Ethylene glycol
151564	Ethylene imine (Aziridine)
75218	Ethylene oxide
96457	Ethylene thiourea
75343	Ethylidene dichloride (1,1-Dichloroethane)
50000	Formaldehyde
76448	Heptachlor
118741	Hexachlorobenzene
87683	Hexachlorobutadiene
77474	Hexachlorocyclopentadiene
67721	Hexachloroethane
822060	Hexamethylene-1,6-diisocyanate
680319	Hexamethylphosphoramide
110543	Hexane
302012	Hydrazine
7647010	Hydrochloric acid
7664393	Hydrogen fluoride (Hydrofluoric acid)
123319	Hydroquinone
78591	Isophorone
58899	Lindane (all isomers)
108316	Maleic anhydride
67561	Methanol
72435	Methoxychlor
74839	Methyl bromide (Bromomethane)

Hazardous Air Pollutants (Air Toxics)	
CAS Number	**Chemical Name**
75569	Propylene oxide
75558	1,2-Propylenimine (2-Methyl aziridine)
91225	Quinoline
106514	Quinone
100425	Styrene
96093	Styrene oxide
1746016	2,3,7,8-Tetrachlorodibenzo-p-dioxin
79345	1,1,2,2-Tetrachloroethane
127184	Tetrachloroethylene (Perchloroethylene)
7550450	Titanium tetrachloride
108883	Toluene
95807	2,4-Toluene diamine
584849	2,4-Toluene diisocyanate
95534	o-Toluidine
8001352	Toxaphene (chlorinated camphene)
120821	1,2,4-Trichlorobenzene
79005	1,1,2-Trichloroethane
79016	Trichloroethylene
95954	2,4,5-Trichlorophenol
88062	2,4,6-Trichlorophenol
121448	Triethylamine
1582098	Trifluralin
540841	2,2,4-Trimethylpentane
108054	Vinyl acetate
593602	Vinyl bromide
75014	Vinyl chloride
75354	Vinylidene chloride (1,1-Dichloroethylene)
1330207	Xylenes (isomers and mixture)
95476	o-Xylenes
108383	m-Xylenes
106423	p-Xylenes
0	Antimony Compounds
0	Arsenic Compounds (inorganic including arsine)
0	Beryllium Compounds
0	Cadmium Compounds
0	Chromium Compounds

Appendix C

AP-42 General Information

Go to the following internet site for ~~the~~ most current AP-42.

http://www.epa.gov/ttn/chief/ap42/index.htm

COMPILATION OF AIR POLLUTANT EMISSION FACTORS

VOLUME I:
STATIONARY POINT AND AREA SOURCES

Introduction

What is an emission factor?

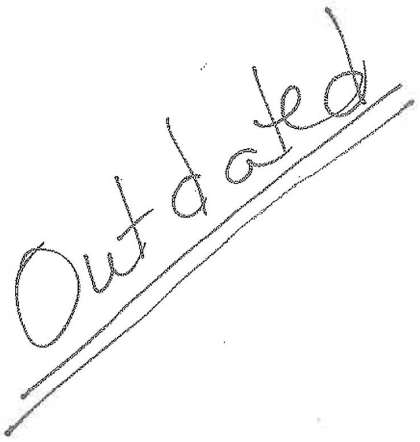
An emission factor is an average value which relates the quantity of a pollutant released to the atmosphere with the activity associated with the release of that pollutant. It is usually expressed as the weight of pollutant divided by a unit weight, volume, distance or duration of the activity that emits the pollutant (e. g., kilograms of particulate emitted per megagram of coal combusted). Using such factors permits the estimation of emissions from various sources of air pollution. In most cases, these factors are simply averages of all available data of acceptable quality, generally without consideration for the influence of various process parameters such as temperature, reactant concentrations, etc. For a few cases, however, such as in the estimation of volatile organic emissions from petroleum storage tanks, this document contains empirical formulae which can relate emissions to such variables as tank diameter, liquid temperature and wind velocity. Emission factors correlated with such variables tend to yield more precise estimates than would factors derived from broader statistical averages.

Recommended uses of emission factors

Emission factors are very useful tools for estimating emissions of air pollutants. However, because such factors are averages obtained from data of wide range and varying degrees of accuracy, emissions calculated this way for a given facility are likely to differ from that facility's actual emissions. Because they are averages, factors will indicate higher emission estimates than are actual for some sources, and lower for others. Only specific source measurement can determine the actual pollutant contribution from a source, under conditions existing at the time of the test. For the most accurate emissions estimate, it is recommended that source specific data be obtained whenever possible. Emission factors are more appropriately used to estimate the collective emissions of a number of sources, such as is done in emissions inventory efforts for a particular geographic area.

If factors are used to predict emissions from new or proposed sources, users should review the latest literature and technology to determine if such sources would likely exhibit emissions characteristics different from those of typical existing sources.

In a few AP-42 Sections, emission factors are presented for facilities having air pollution control equipment in place. These factors are not intended to be used as regulatory standards. They do not represent best available control technology (BACT), such as may be reflected in New Source Performance Standards (NSPS), or reasonably available control technology (RACT) for existing sources . Rather, they relate to the average level of controls found on existing facilities for which data are available. The usefulness of this information should be considered carefully, in light of changes in air pollution control technology. In using this information with respect to any specific

Appendix D

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